Testing the CGC with RHIC forward data

Javier L Albacete

cnrs IN2P3 Les deux infinis

IPN ORSAY

UNIVERSITÉ PARIS SUD

Workshop on Forward Physics at RHIC, Jul-30-Aug 1st
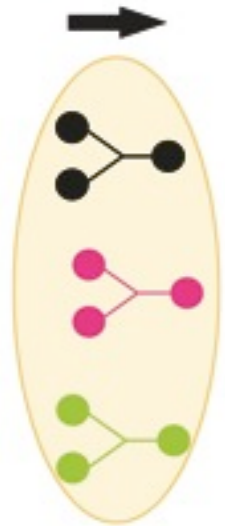**Brookhaven National Lab**

What the CGC is about : coherence effects in high energy QCD (small-x)

High gluon densities in the projectile/target

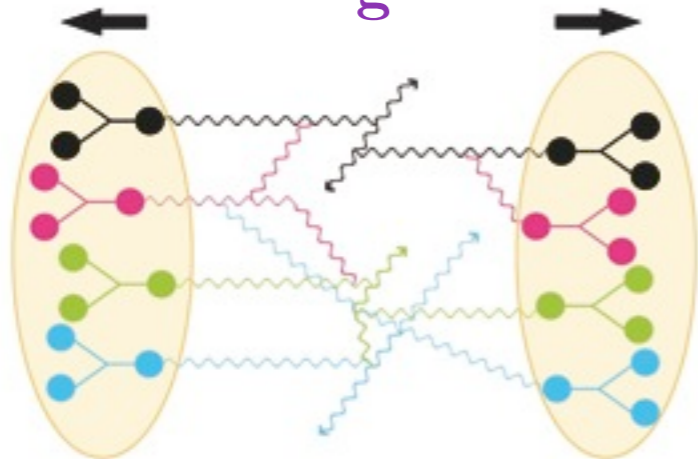Saturation: gluon self-interactions tame the growth of gluon densities towards small-x

$$\frac{\partial \phi(\mathbf{x}, \mathbf{k_t})}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k_t}) - \phi(\mathbf{x}, \mathbf{k_t})^2$$

radiation   recombination

$$\mathbf{k_t} \lesssim \mathbf{Q_s}(\mathbf{x})$$

Breakdown of independent particle production

$$\mathcal{A}(\mathbf{k} \lesssim \mathbf{Q_s}) \sim \frac{\mathbf{1}}{\mathbf{g}} \qquad \mathbf{g}\mathcal{A} \sim \mathcal{O}(\mathbf{1})$$
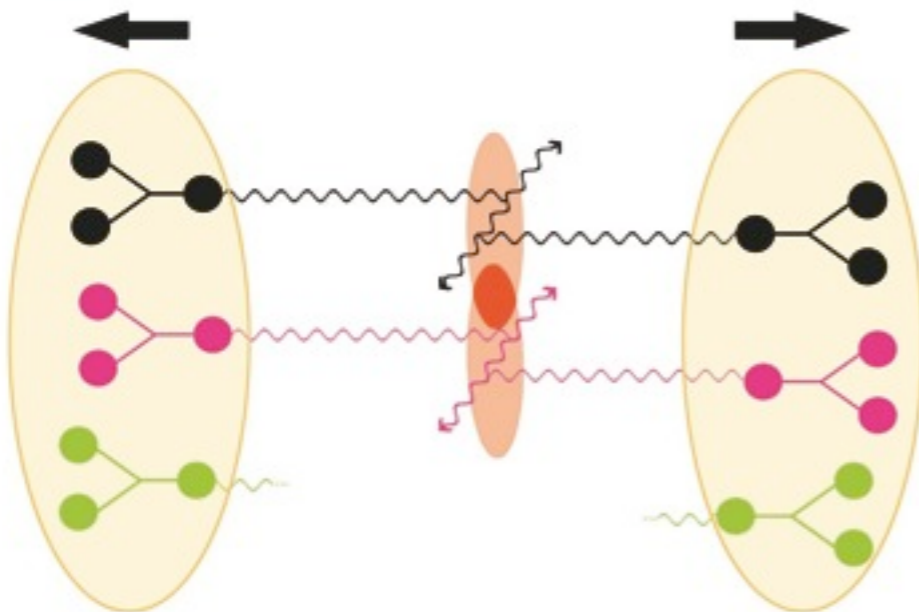
What the CGC is about : coherence effects

High gluon densities in the projectile/target

Saturation: gluon self-interactions tame the growth of gluon densities towards small-x

$$\frac{\partial \phi(\mathbf{x}, \mathbf{k_t})}{\partial \ln(\mathbf{x_0}/\mathbf{x})} \approx \mathcal{K} \otimes \phi(\mathbf{x}, \mathbf{k_t}) - \phi(\mathbf{x}, \mathbf{k_t})^2$$
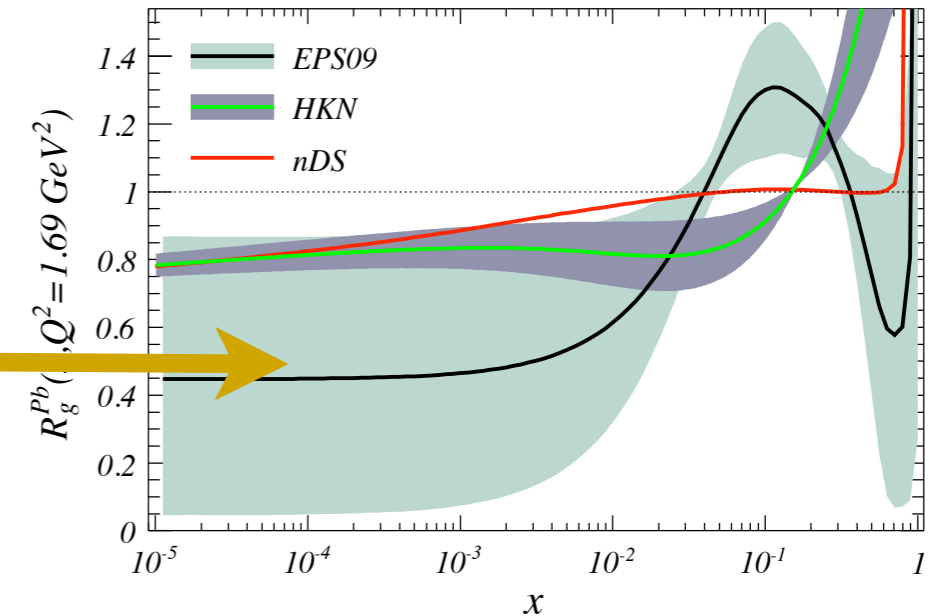
radiation   recombination

$$\mathbf{k_t} \lesssim \mathbf{Q_s(x)}$$
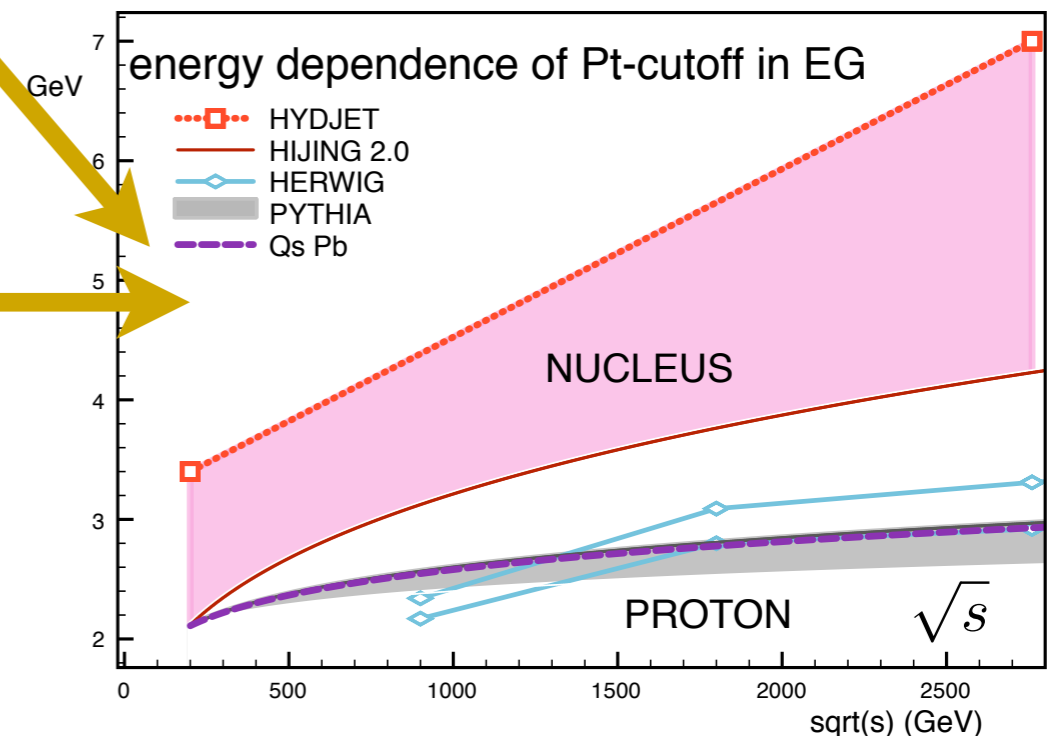
Breakdown of independent particle production

HIC phenomenology

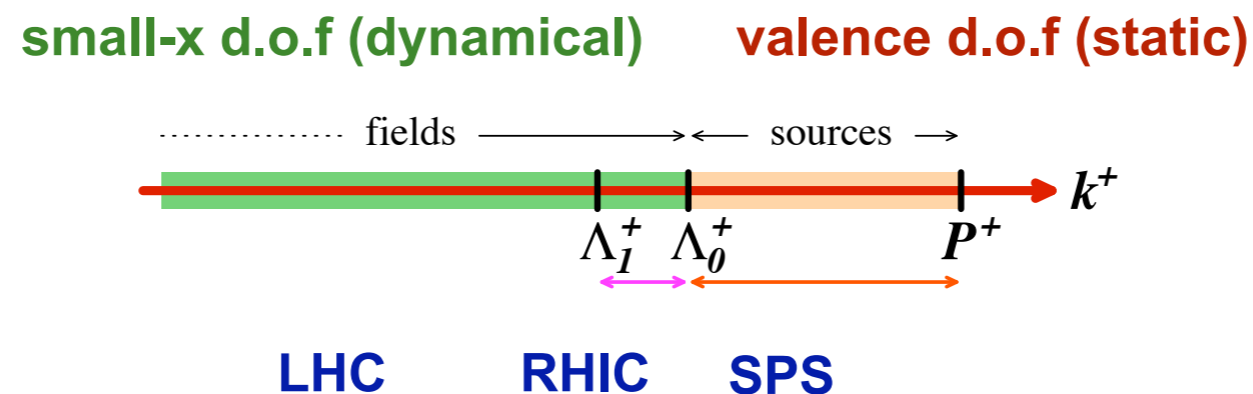• Nuclear shadowing, String fusion, percolation

• Resummation of multiple scatterings
• kt-broadening
• Energy dependent cutoff in event generators

energy dependence of Pt-cutoff in EG

HYDJET
HIJING 2.0
HERWIG
PYTHIA
Qs Pb

NUCLEUS

PROTON $\sqrt{s}$

3

OUTLINE

• Coherence effects are essential for the description of data in HIC collisions (RHIC, LHC)

• The presence of a semi-hard dynamical scale --the saturation scale-- + non-linear dynamics led to semi-quantitative predictions later confirmed by data

    - ~ Npart scaling and energy dependence of total multiplicties Kharzeev-Levin-Nardi   JLA-Armesto-
    - Continuos depletion of nuclear modification factors with increasing hadron rapidity in dA collisions Kovner-Salgado-
    - Angular decorrelation of hadron pairs produced at forward rapidities in dA collisions Marquet   Wiedeman

• Getting quantitative: Is the CGC effective theory (at its present degree of accuracy) the best suited framework to quantify coherence phenomena in HI collisions at RHIC and the LHC?

    - Control of missing dynamical effects: are RHIC and LHC energies large enough for the applicability of the CGC?
    - Control of higher order terms in the perturbative series
    - Do we have enough empiric info (i.e. data) to constrain the NP parameters of the theory?

small-x d.o.f (dynamical)   **valence d.o.f (static)**

fields $\longrightarrow$ $\longleftarrow$ sources $\longrightarrow$

Λ_1^+ Λ_0^+ P^+ k^+

LHC   **RHIC**   **SPS**

Color Glass Condensate phenomenology tools (in half a slide)

1.- (classical) Ab initio calculation of nuclear structure functions (small-x gluon distributions)

McLerran-Venugopalan model ($x_0 \sim 0.01$). Valid for large nucleus $gA^{1/3} \gg 1$

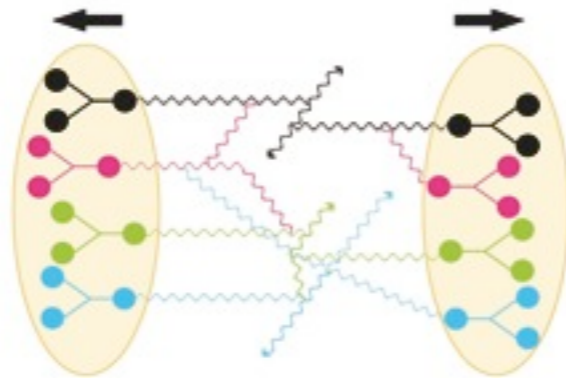**2.-** (quantum) Nonlinear renormalization group equations towards small-x

BK-JIMWLK eqns ($x < x_0 \sim 0.01$)
$$\frac{\partial \phi(x,k)}{\partial \ln(1/x)} = \mathcal{K} \otimes \phi(x,k) - \phi^2(x,k) \qquad \frac{\partial V[\rho]}{\partial Y} = \ldots$$

3.- Production processes
$$\frac{dN^{AB \to X}}{d^3 p_1 \ldots} [\phi(x,k); W_Y[\rho]]$$
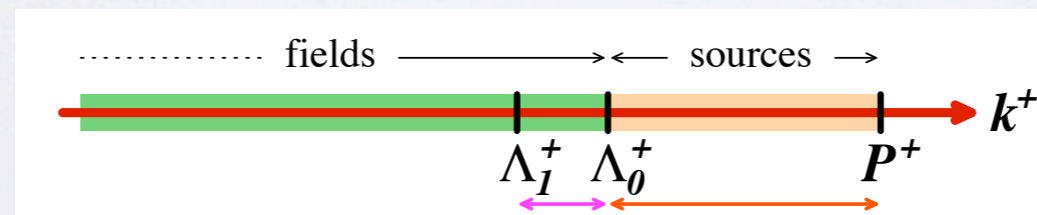
CYM,
kt-factorization
hybrid formalism...

$$\mathcal{A}(\mathbf{k} \lesssim \mathbf{Q_s}) \sim \frac{1}{g}$$

$$g\mathcal{A} \sim \mathcal{O}(1)$$

The eikonal (recoil-less) approximation is central in the CGC:

small-x d.o.f (dynamical)　　valence d.o.f (static)

fields ⋯⋯⋯⋯⋯ →←— sources →

$$\Lambda_1^+ \quad \Lambda_0^+ \qquad P^+ \qquad k^+$$

LHC　　　**RHIC**　**SPS**

CGC Theory Status: Entering the NLO era

Evolution Equations:
$$\frac{\partial\,\phi(x,k)}{\partial\,\ln(1/x)} = \mathcal{K} \otimes \phi(x,k) - \phi^2(x,k) \qquad \frac{\partial\,W[\rho]}{\partial\,Y} = \ldots$$

✓ - Running coupling kernel in BK evolution for the 2-point function *Kovchegov Weigert Gardi*
Balitsky

✗ - Full NLO kernel for BK-JIMWLK [Balitsky Chirilli]

✗ - Analytic [Triantafyllopoulos] and numerical [T. Lappi et.al] solutions of
full B-JIMWLK hierarchy for n-point functions

- ...

LO: $\alpha_s \ln(1/x)$　　　NLO　　　Running coupling
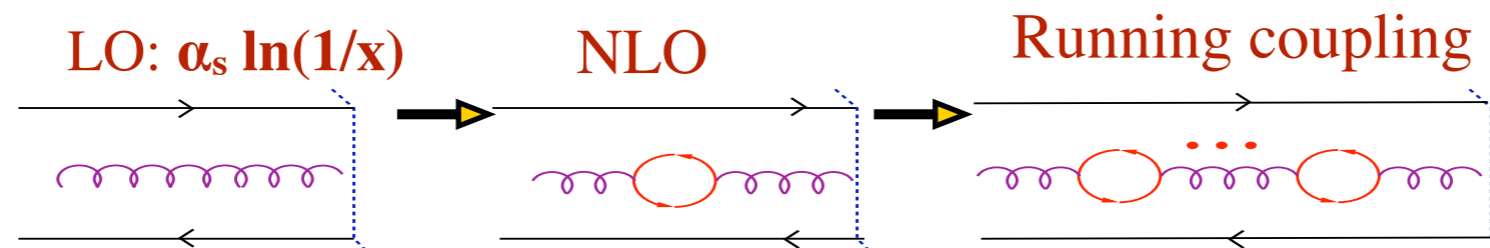
Production processes $\quad \dfrac{dN^{AB\to X}}{d^3 p_1 \ldots}\,[\phi(x,k);W_Y[\rho]]$

✗ - Running coupling and full NLO corrections to kt-factorization [Kovchegov, Horowitz, Balitsky, Chirilli]

✓ - Inelastic terms in the hybrid formalism [Kovner-Altinoluk]

✓ - Hadron-hadron, hadron-photon* correlations

✗ - Factorization of multiparticle production processes at NLO

✗ - DIS NLO photon impact factors [Chirilli]

- ...

Used in phenomenological works? ✓ Yes ✗ No ✓ A bit :)

Data??

Empiric information needed to constrain:

- Non-perturbative parameters: initial conditions for BK-JIMWLK evolution, impact parameter
- K-factors to account for higher order corrections (effectively also for missing high-$(x,Q2)$ contributions, energy-conservation corrections etc)
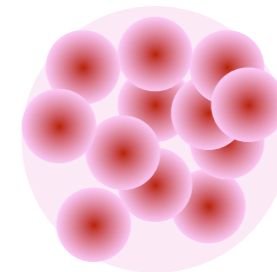
:) **proton**

- Abundant high quality data at small-x
- Good simultaneous description of e+p and p+p data
- Global rcBK fits to constrain gluon distribution

:| **nucleus**

- Fewer data at small-x
- LHC Pb+Pb data (difficult...)
- EIC and pPb @ LHC data to come...
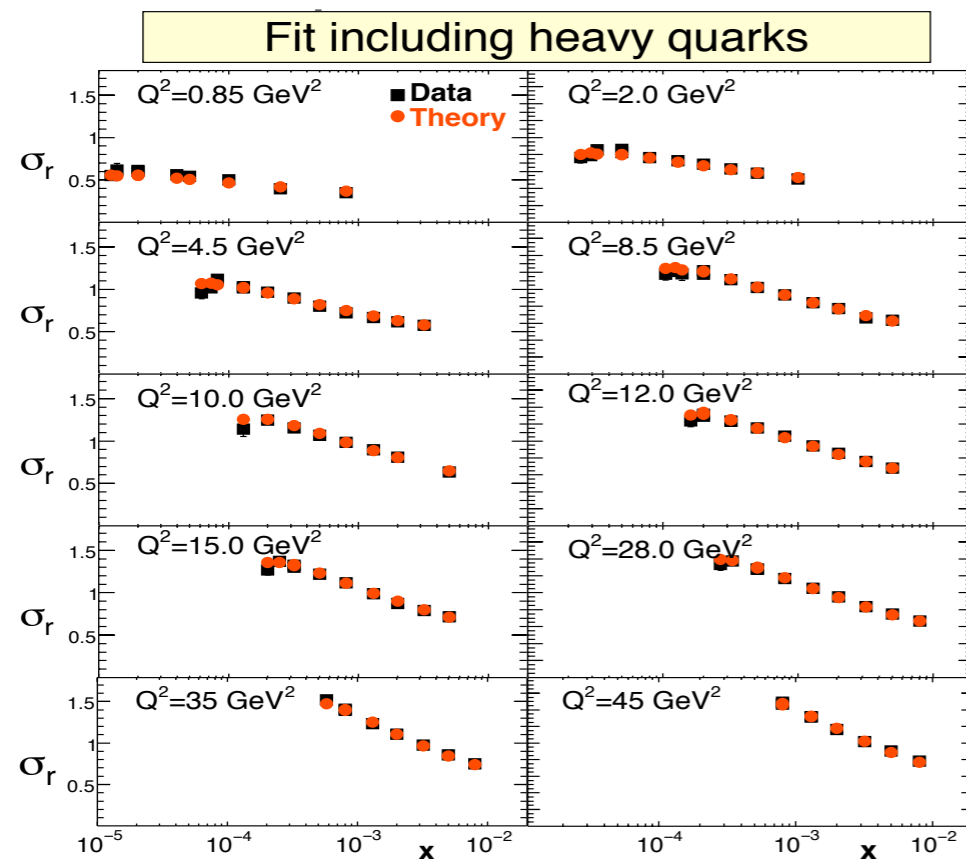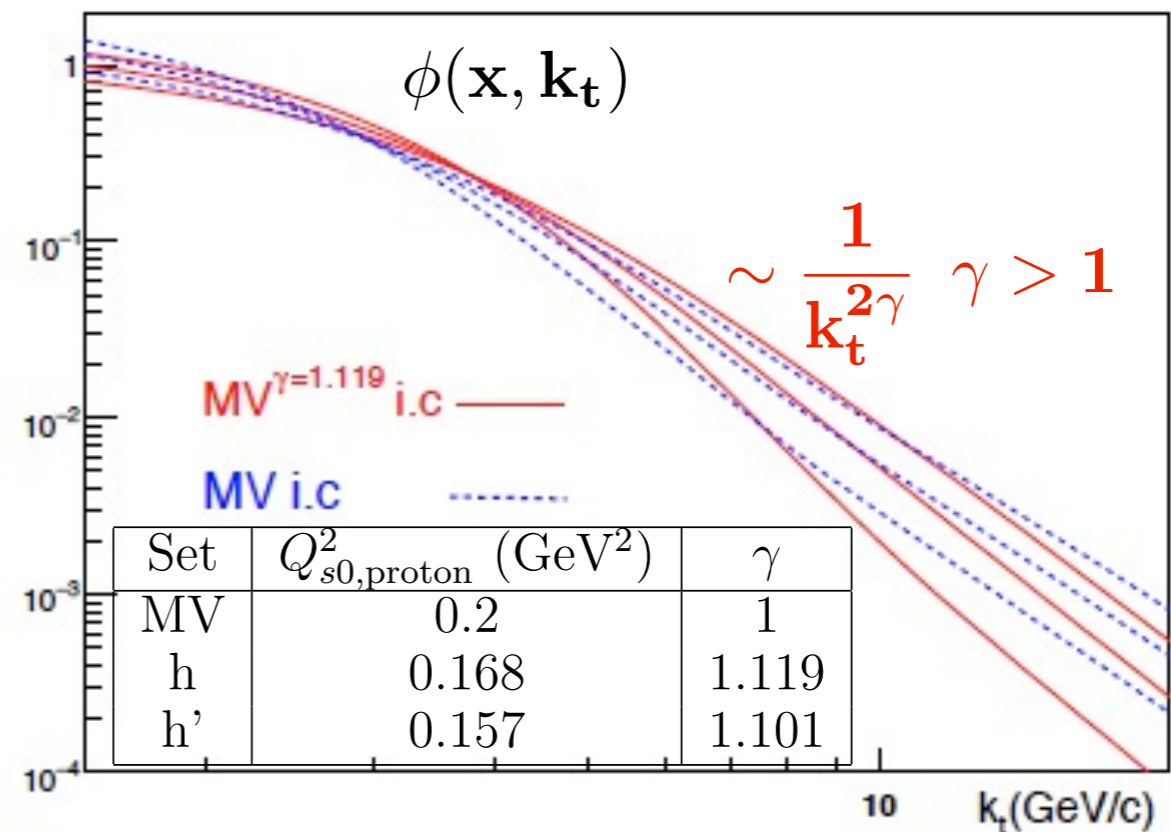- RHIC dAu forward data provides the best testing ground of the CGC

modelling!

1. Global fits to e+p data at small-x

2. Extract NP fit parameters

Fit including heavy quarks

JLA-Armesto-Milhano-Quiroga-Salgado

$\phi(\mathbf{x}, \mathbf{k_t})$

$\sim \dfrac{1}{\mathbf{k_t^{2\gamma}}} \quad \gamma > 1$

MV$^{\gamma=1.119}$ i.c ——

MV i.c ┈┈┈┈┈

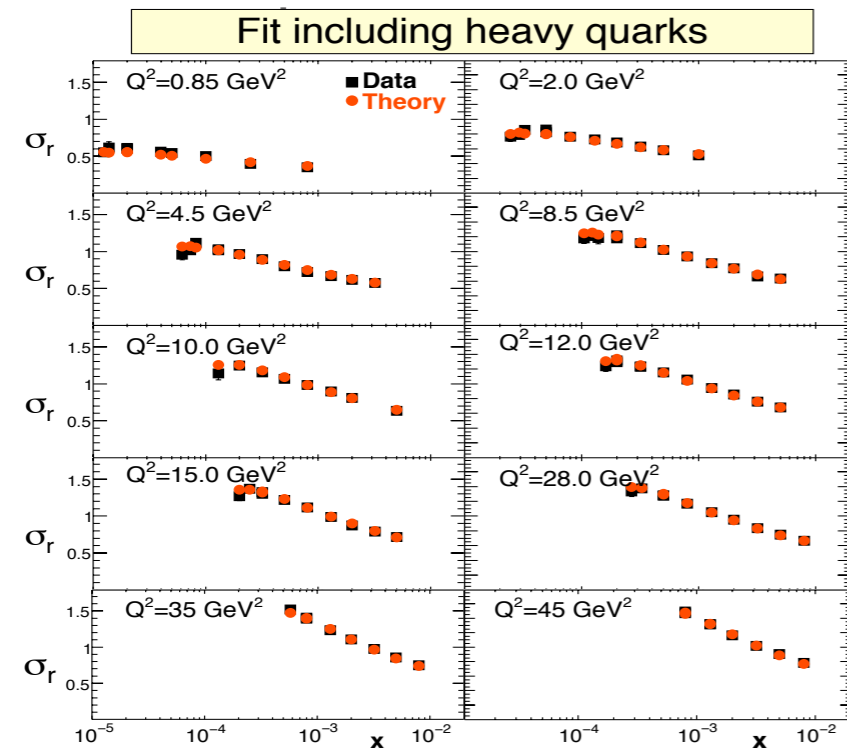| Set	$Q_{s0,\text{proton}}^2$ (GeV^2)	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

$$\mathcal{N}^{MV}(r, x_0 = 10^{-2}) = 1 - \exp\left[-\left(\frac{r^2\, Q_{s0}^2}{4} \right)^{\gamma} \ln\left(\frac{1}{r\, \Lambda_{QCD}} \right) \right]$$

- Fits to e+p data clearly prefer gamma>1.
- MV (gamma=1) model seems not to work well for protons...
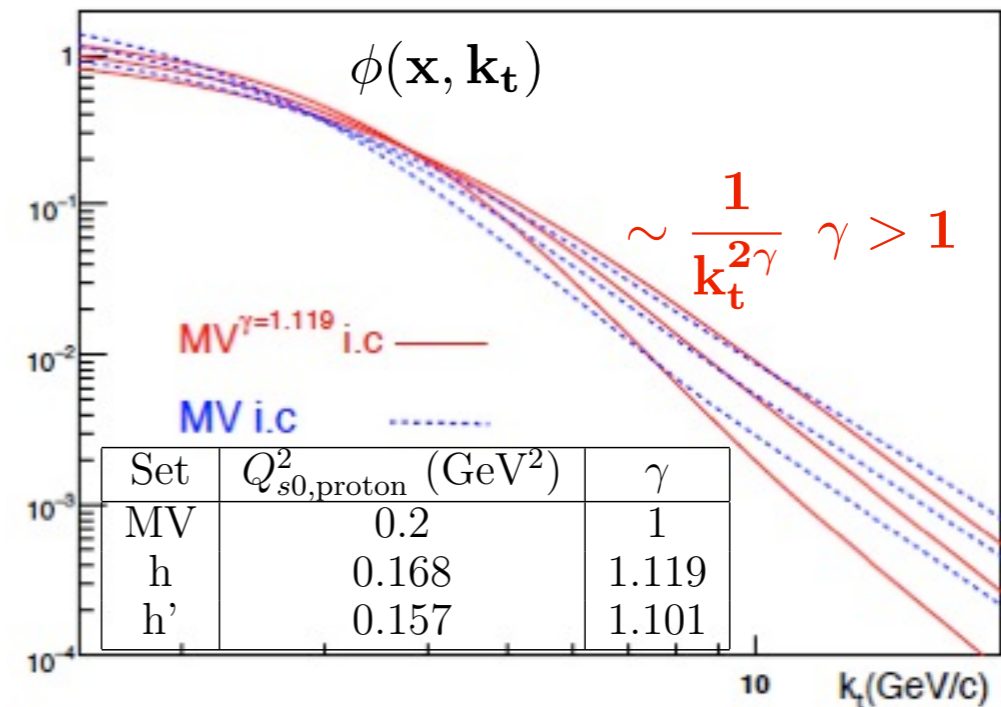- Possible explanation: subleading in density corrections to the MV model yield gamma> 1 Dumitru & Pereska 11

Talk by P. Quiroga

1. Global fits to e+p data at small-x

Fit including heavy quarks

2. Extract NP fit parameters

$\phi(\mathbf{x}, \mathbf{k_t})$

$$\sim \frac{1}{k_t^{2\gamma}} \quad \gamma > 1$$

$MV^{\gamma=1.119}$ i.c ——

MV i.c ·······

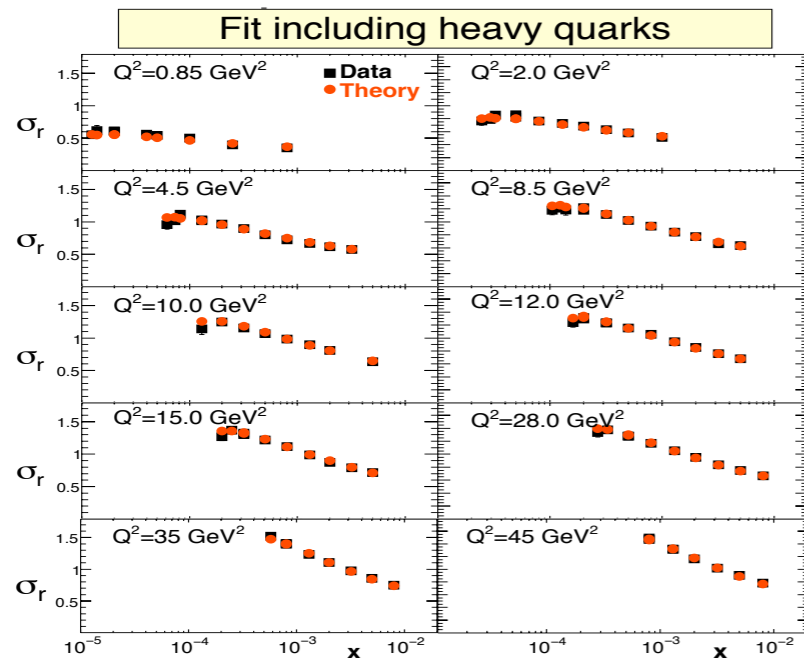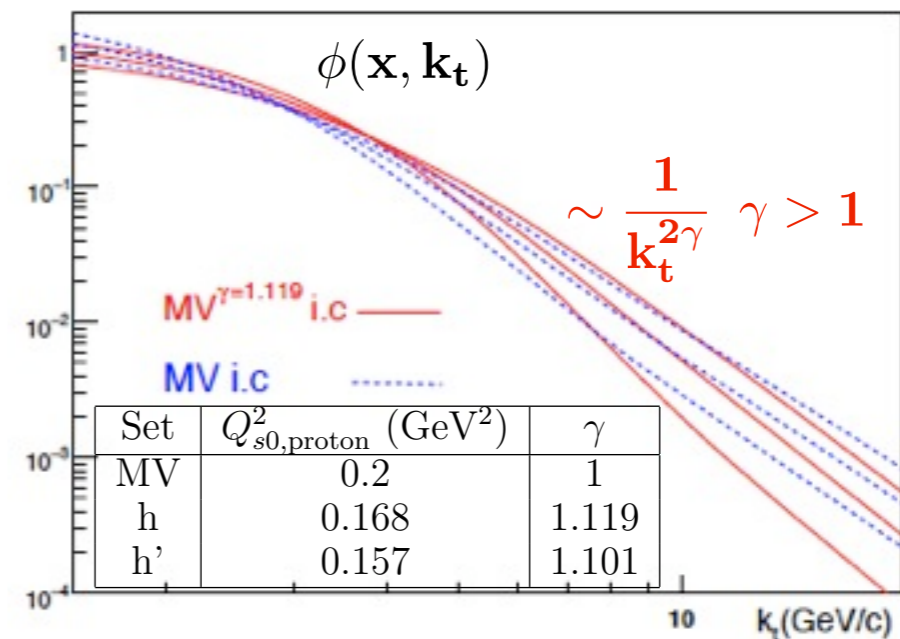| Set	$Q^2_{s0,proton}$ (GeV^2)	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

3. Run consistency and stability checks
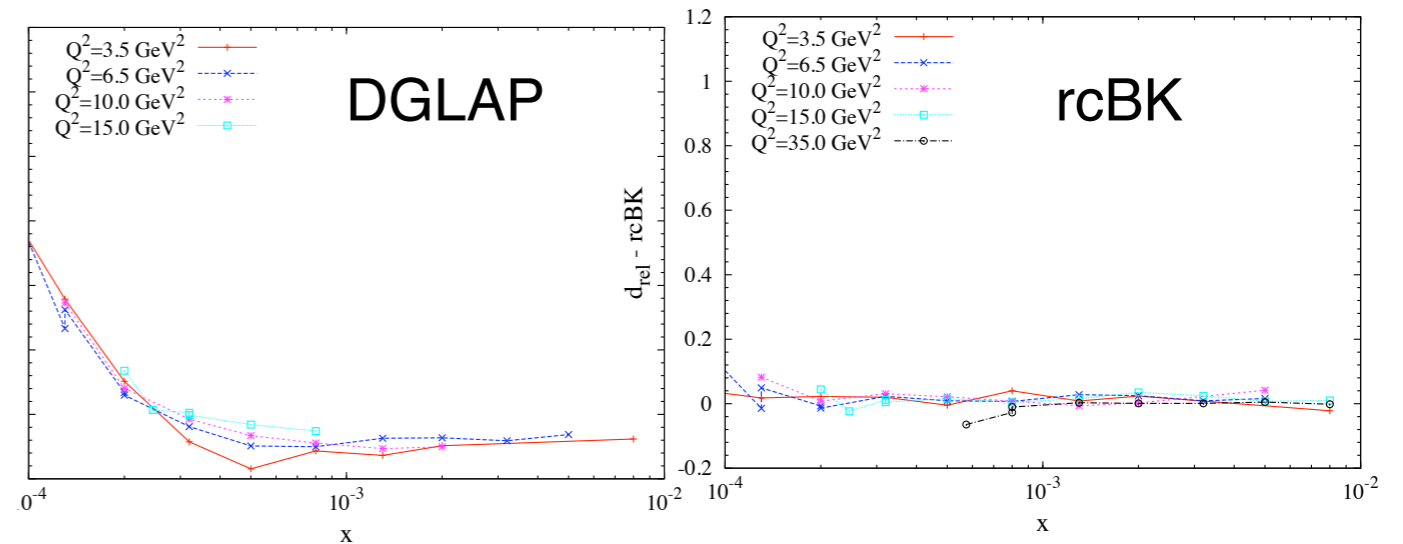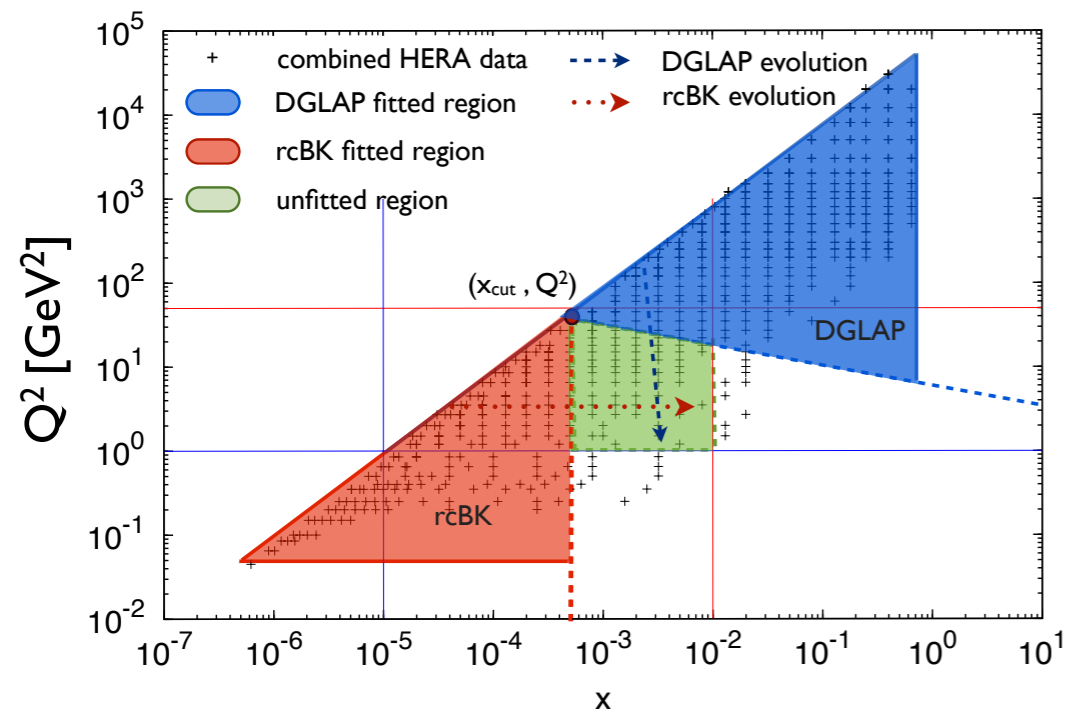
DGLAP

rcBK

rcBK fits more stable than DGLAP fits at small-x!!!

The baseline: proton collisions
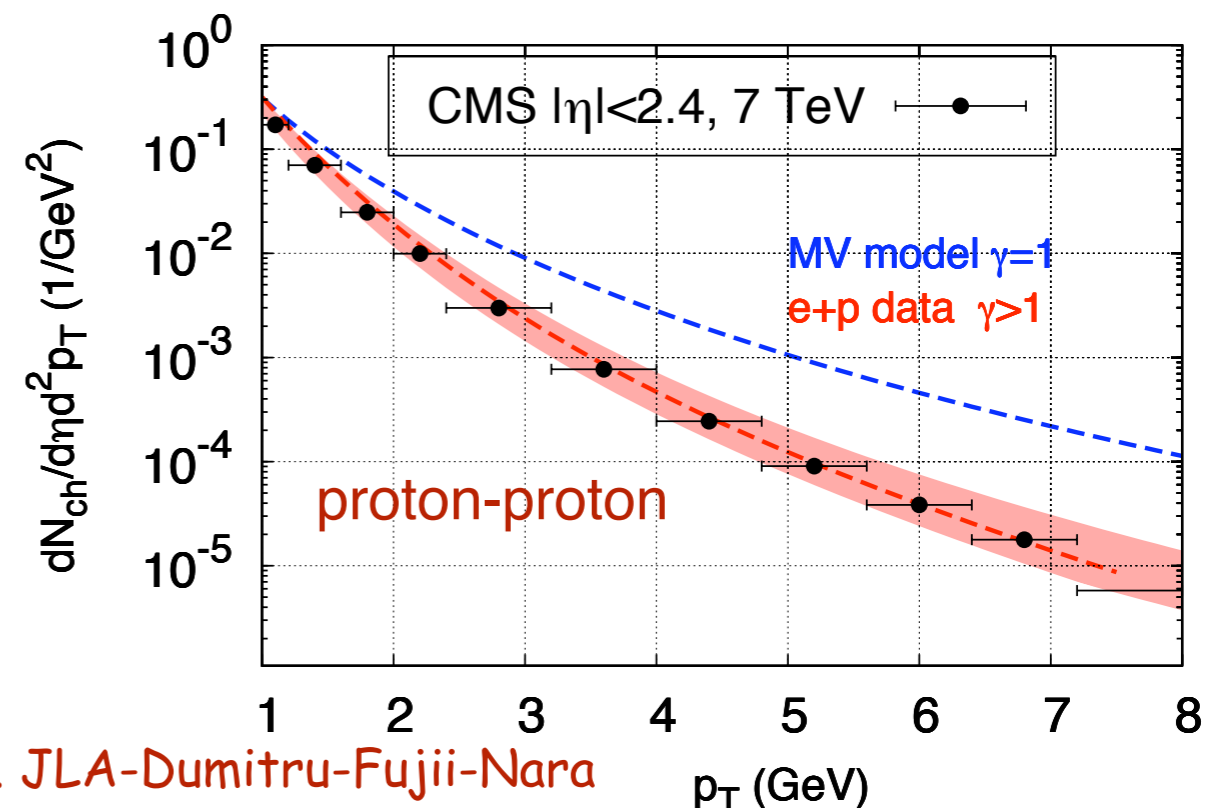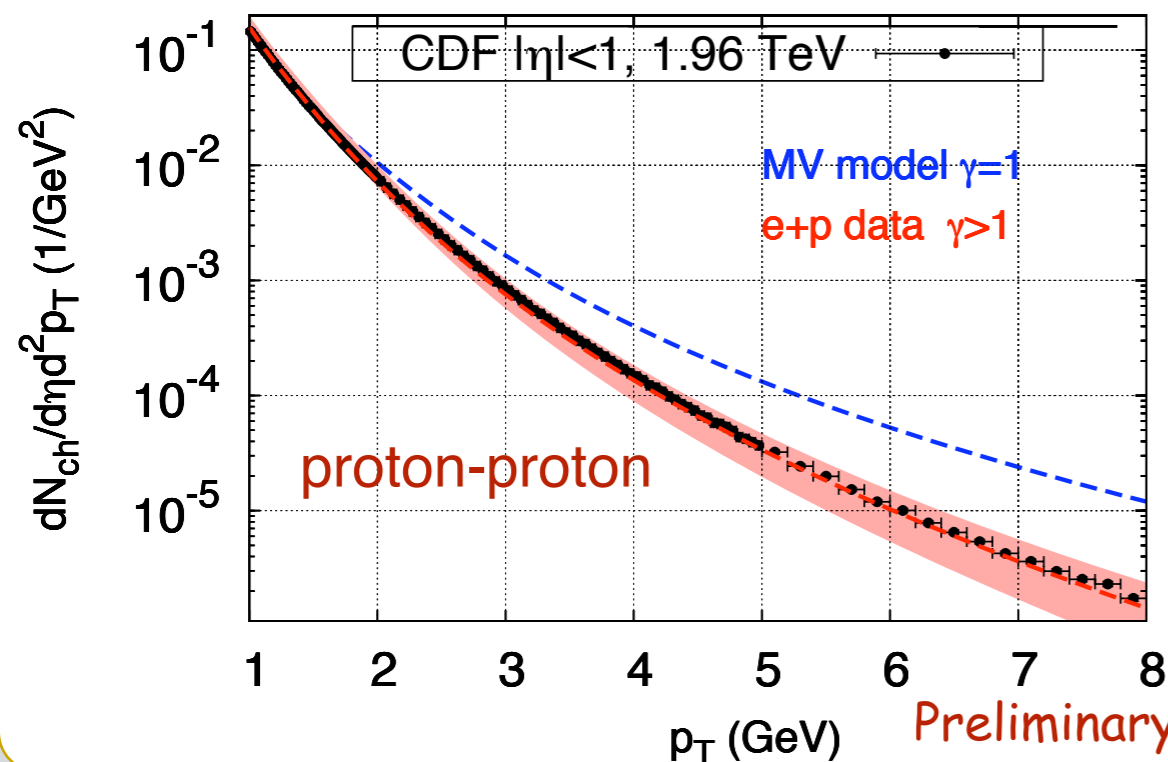
1. Global fits to e+p data at small-x

Fit including heavy quarks

$Q^2=0.85\ \text{GeV}^2$ ■ Data ● Theory
$Q^2=2.0\ \text{GeV}^2$
$Q^2=4.5\ \text{GeV}^2$
$Q^2=8.5\ \text{GeV}^2$
$Q^2=10.0\ \text{GeV}^2$
$Q^2=12.0\ \text{GeV}^2$
$Q^2=15.0\ \text{GeV}^2$
$Q^2=28.0\ \text{GeV}^2$
$Q^2=35\ \text{GeV}^2$
$Q^2=45\ \text{GeV}^2$

2. Extract NP fit parameters

$\phi(\mathbf{x}, \mathbf{k_t})$

$\sim \dfrac{1}{\mathbf{k_t^{2\gamma}}}\quad \gamma > 1$

$MV^{\gamma=1.119}$ i.c ——

MV i.c ·······

Set	$Q^2_{s0,\text{proton}}\ (\text{GeV}^2)$	γ
MV	0.2	1
h	0.168	1.119
h'	0.157	1.101

k_t (GeV/c)

4. Apply gained knowledge in the study of other systems (theory driven extrapolation)

LO kt-factorization:
$$\dfrac{\mathbf{dN^g}}{\mathbf{d\eta\, d^2 p_t}} \sim \mathbf{K}\,\alpha_s(\mathbf{Q_r^2})\,\phi(\mathbf{x_1}, \mathbf{k_t}) \otimes \phi(\mathbf{x_2}, \mathbf{k_t} - \mathbf{pt}) \otimes \mathrm{FF}(Q_f^2)$$

CDF |η|<1, 1.96 TeV

MV model γ=1
e+p data γ>1

proton-proton

$dN_{ch}/d\eta d^2 p_T\ (1/\text{GeV}^2)$
p_T (GeV)

CMS |η|<2.4, 7 TeV

MV model γ=1
e+p data γ>1

proton-proton

$dN_{ch}/d\eta d^2 p_T\ (1/\text{GeV}^2)$
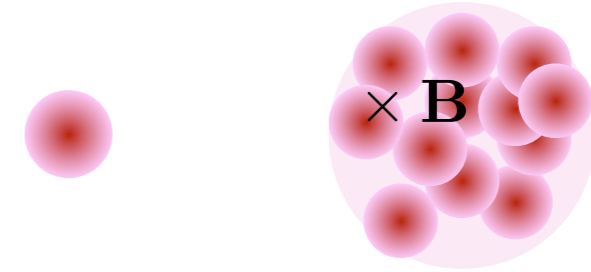p_T (GeV)

Preliminary results. JLA-Dumitru-Fujii-Nara

Nuclear ugd's and nuclear modification factors

1. Setting up the evolution

$$\phi^{\mathbf{Pb}}(\mathbf{x_0}, \mathbf{k_t}, \mathbf{B}) = \phi^{\mathbf{p}}(\mathbf{x_0}, \mathbf{k_t}; \{\mathbf{Q^2_{s0,p}} \to \mathbf{Q^2_{s0,Pb}}(\mathbf{B})); \gamma\}$$
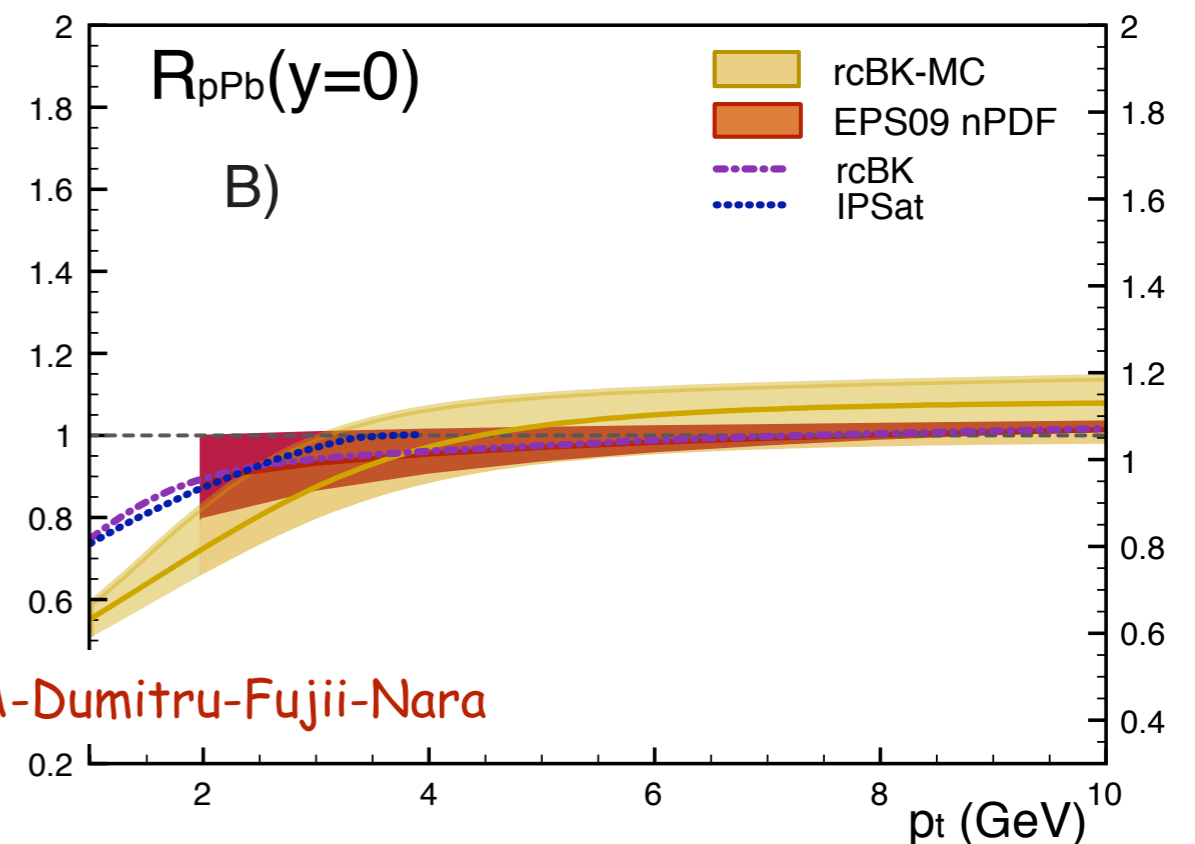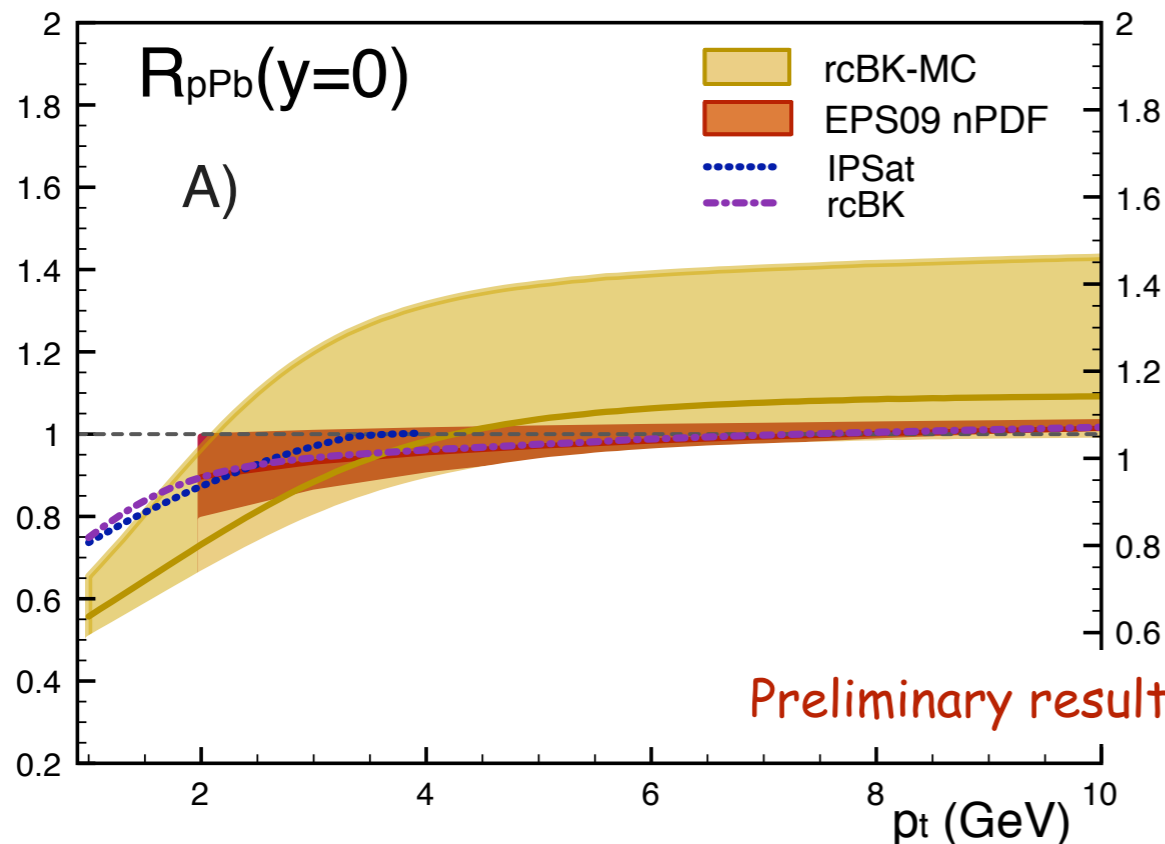
$$\phi^{\mathbf{Pb}}(\mathbf{x}, \mathbf{k_t}, \mathbf{B}) = \mathbf{rcBK}[\phi^{\mathbf{Pb}}(\mathbf{x_0}, \mathbf{k_t}, \mathbf{B})]$$

A) Most "natural" option: $\mathbf{Q^2_{s0,Pb}}(\mathbf{B}) = \mathbf{T_A}(\mathbf{B})\, \mathbf{Q^2_{s0,p}}$ $\qquad \gamma^{\mathbf{Pb}} = \gamma^{\mathbf{p}}(> 1)$

PROBLEM: yields $R_{pPB} > 1$ at high transverse momentum

B) Possible solution $\quad \mathbf{Q^2_{s0,Pb}}(\mathbf{B}) = \mathbf{T_A}(\mathbf{B})^{1/\gamma}\, \mathbf{Q^2_{s0,p}}$ and/or $\quad \gamma^{\mathbf{Pb}} = \mathbf{1}(\mathbf{MV}) + \dfrac{\#}{\mathbf{A^2/3}}$
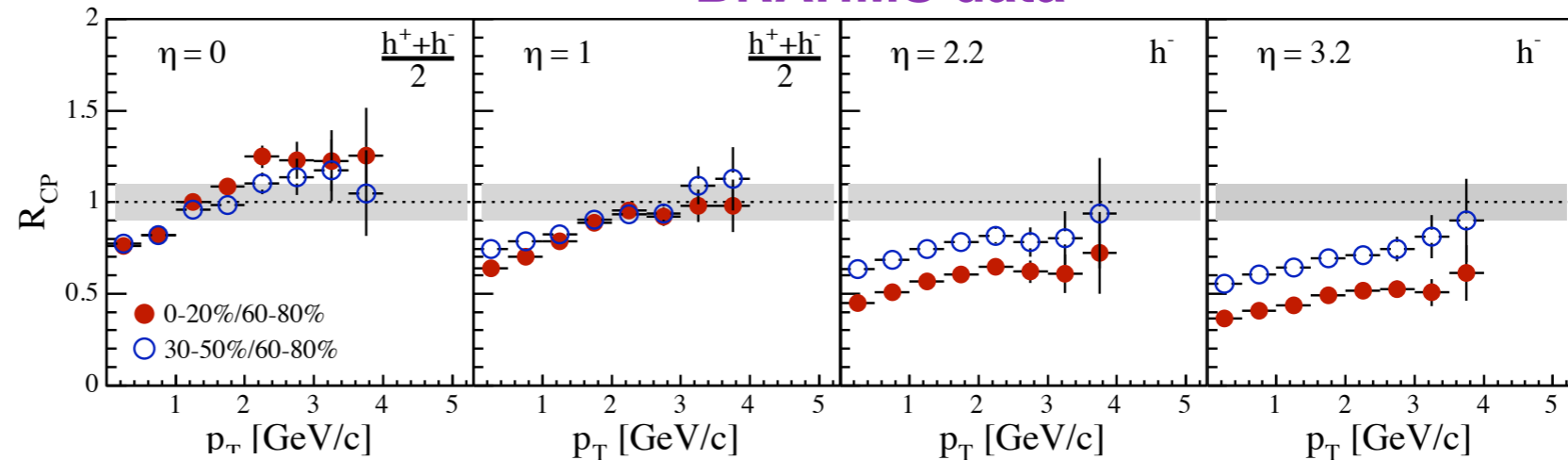

Preliminary results. JLA-Dumitru-Fujii-Nara

Single inclusive forward particle production in p(d)-A collisions

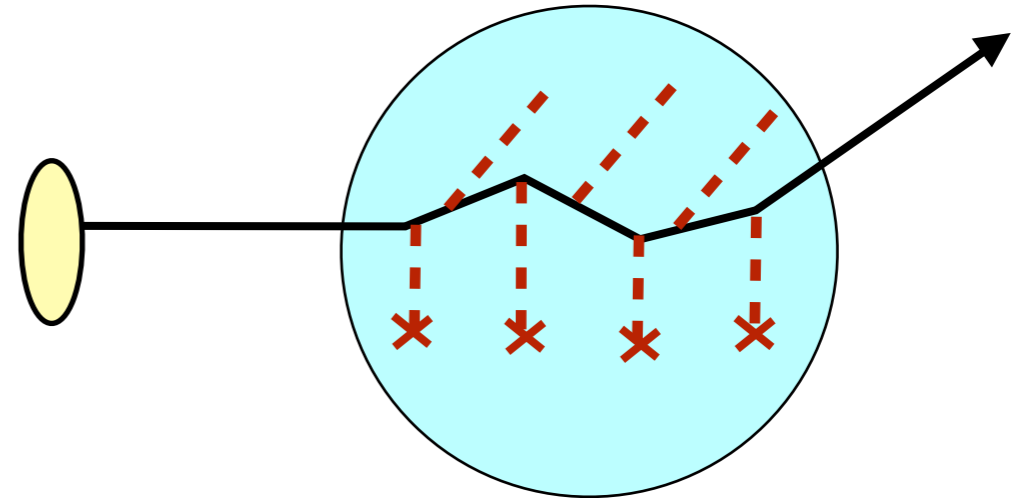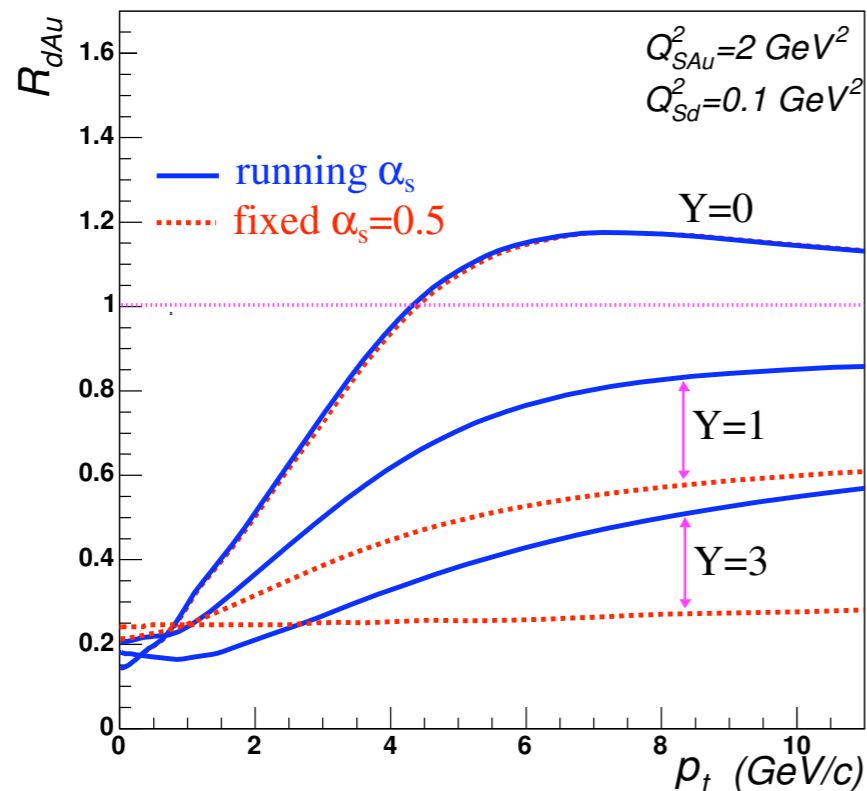$$R_{pA} = \frac{\frac{dN_{pA}}{dyd^2pd^2b}}{A^{1/3}\frac{dN_{pp}}{dyd^2pd^2b}}$$

- **CGC**: Forward suppression originates in the dynamical shadowing generated by the quantum non-linear BK-JIMWLK evolution towards small-x

- Alternative: **Energy loss** arising from induced gluon bremstahlung (stronger in nucleus than in proton)

Non-Linear Evolution of Cronin Enhancement

Probability of not losing energy:

$$P(\Delta y) \approx e^{-n_G(\Delta y)} \approx (1 - x_F)^{\#}$$

Kopeliovich et al, Frankfurt Strikman

Single inclusive forward particle production in p(d)-A collisions

Hybrid formalism (Dumitru-Jalilian-Marian):

$$x_{1(2)} \sim \frac{m_t}{\sqrt{s}} \exp(\pm y_h)$$

$(p_t, y_h \gg 0)$

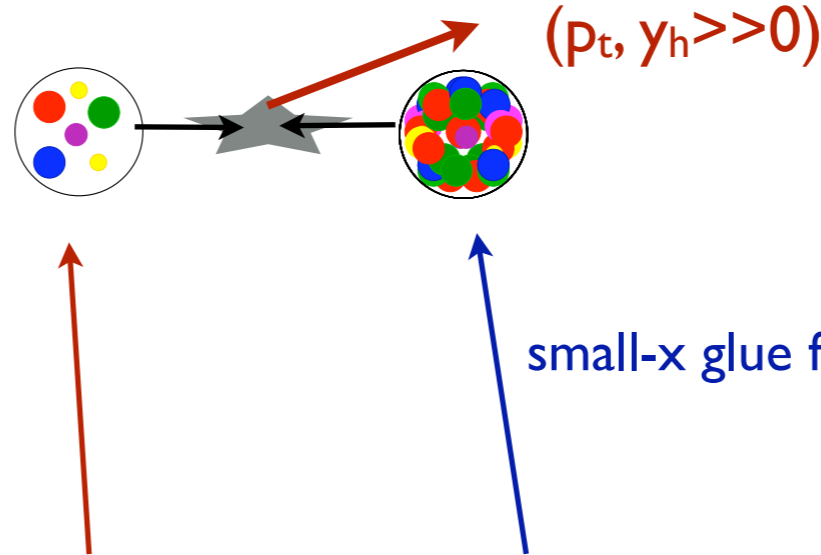large-x parton from proj. (pdf)

small-x glue from target (CGC)

$$\frac{dN_h}{dy_h \, d^2 p_t} = \frac{K}{(2\pi)^2} \sum_q \int_{x_F}^1 \frac{dz}{z^2} \left[x_1 f_{q/p}(x_1, p_t^2) \, \tilde{N}_F\left(x_2, \frac{p_t}{z}\right) D_{h/q}(z, p_t^2) \right.$$

fragmentation

$$\left. + x_1 f_{g/p}(x_1, p_t^2) \, \tilde{N}_A\left(x_2, \frac{p_t}{z}\right) D_{h/g}(z, p_t^2) \right]$$

Single inclusive forward particle production in p(d)-A collisions

Hybrid formalism (Dumitru-Jalilian-Marian):

$$x_{1(2)} \sim \frac{m_t}{\sqrt{s}} \exp(\pm y_h)$$

(p$_t$, y$_h$>>0)

large-x parton from proj. (pdf)

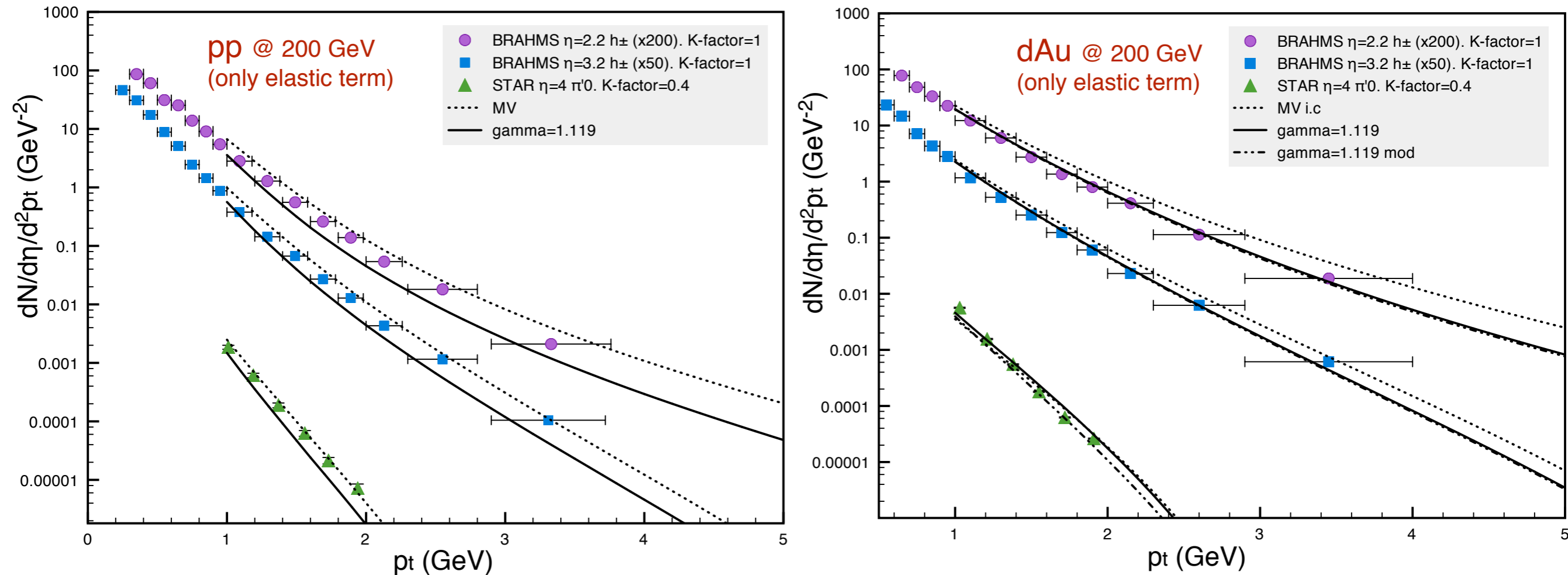small-x glue from target (CGC)

"elastic" term:

$$\frac{dN_h}{dy_h \, d^2 p_t} = \frac{K}{(2\pi)^2} \sum_q \int_{x_F}^1 \frac{dz}{z^2} \left[x_1 f_{q/p}(x_1, p_t^2) \, \tilde{N}_F\left(x_2, \frac{p_t}{z}\right) D_{h/q}(z, p_t^2) \right.$$

fragmentation

$$\left. + \, x_1 f_{g/p}(x_1, p_t^2) \, \tilde{N}_A\left(x_2, \frac{p_t}{z}\right) D_{h/g}(z, p_t^2) \right]$$

+"inelastic" term (Altinoluk-Kovner): (Part of the NLO corrections)

$$+ \, \frac{\alpha_s(Q)}{2\pi^2} \int_{x_F}^1 \frac{dz}{z^2} \frac{z^4}{k^4} \int^Q \frac{d^2 q}{(2\pi)^2} q^2 \tilde{N}_F(x_2, q) x_1 \int_{x_1}^1 \frac{d\xi}{\xi} \sum_{i,j=q,\bar{q},g} w_{i/j}(\xi) P_{i/j}(\xi) f_j(\frac{x_1}{\xi}, Q^2) D_{h/j}(z, Q^2)$$

Single inclusive forward particle production in p(d)-A collisions

Good description of pp an dAu RHIC forward data using only the "elastic" LO term

pp @ 200 GeV
(only elastic term)

dAu @ 200 GeV
(only elastic term)

Legend (both panels):
- ● BRAHMS η=2.2 h± (x200). K-factor=1
- ■ BRAHMS η=3.2 h± (x50). K-factor=1
- ▲ STAR η=4 π'0. K-factor=0.4
- ⋯ MV (left) / MV i.c (right)
- — gamma=1.119
- –·– gamma=1.119 mod (right only)

JLA-Marquet '10; JLA-Dumitru-Fujii-Nara (preliminary)

- However, RHIC data do not allow to determine the best i.c. for the nuclear UGD
- K-factor ~ 0.4 needed to describe the most forward pion data

Single inclusive forward particle production in p(d)-A collisions

NLO corrections brought by the "inelastic piece" may be large (preliminary results!!)

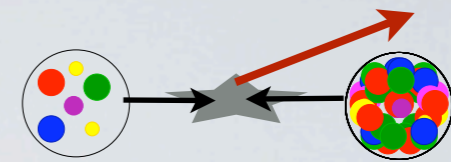JLA-Dumitru-Fujii-Nara (preliminary)

Jalilian-Marian Rezaeian '11
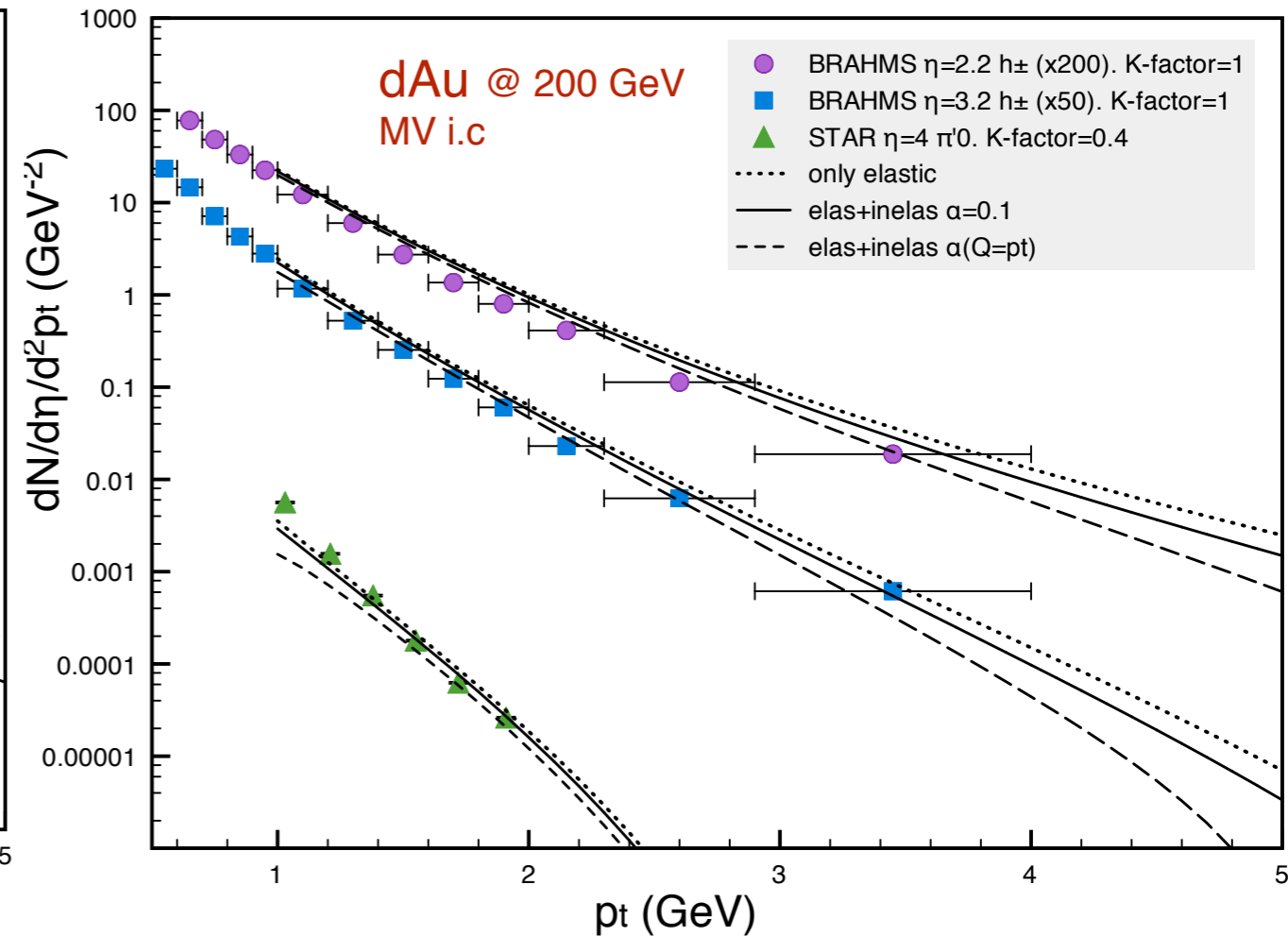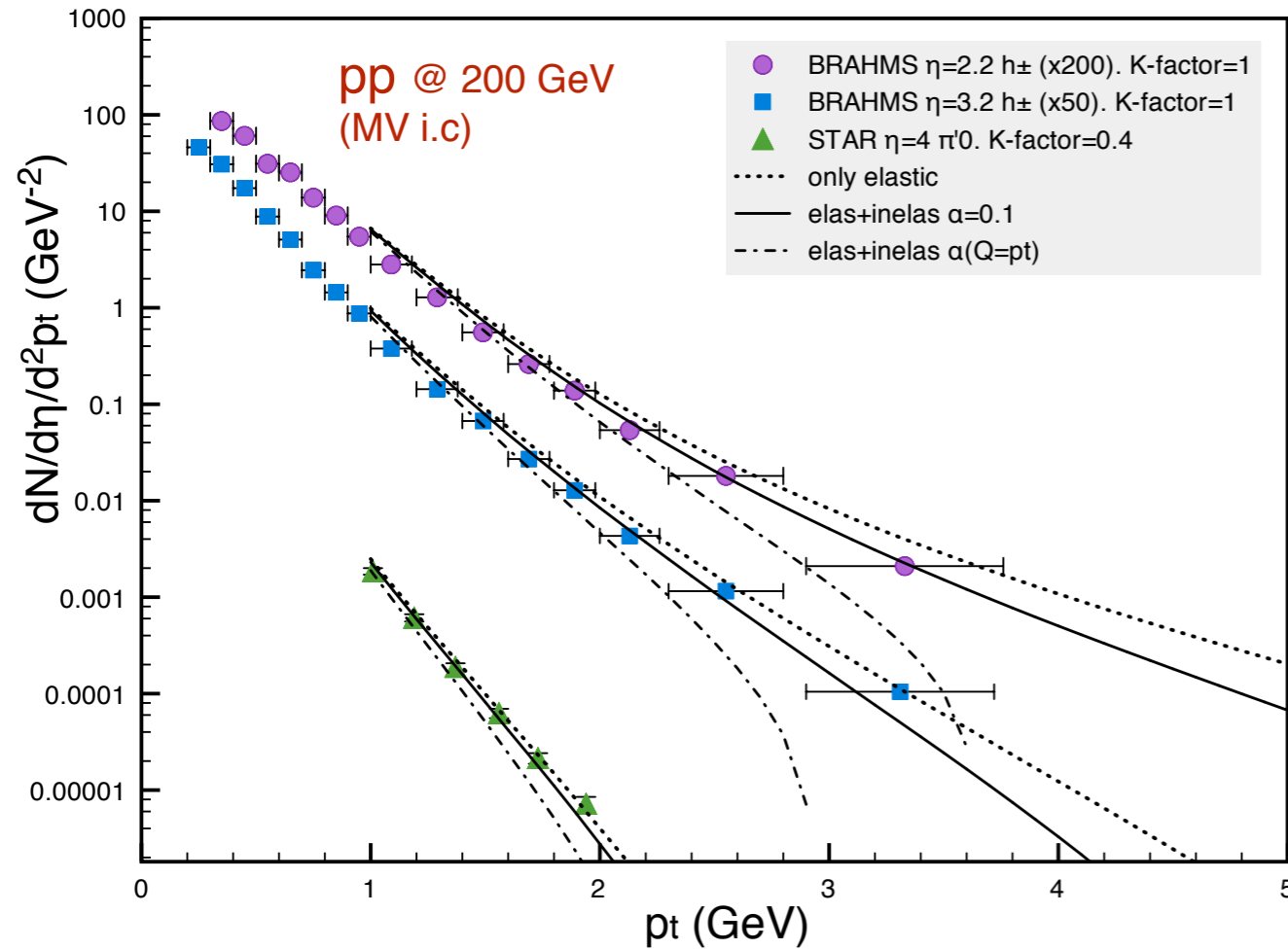
- The inelastic term is negative for all values (y,pt) explored in our work.
- Its relative magnitude wrt the elastic term decreases at small pt or forward rapidities
- Changes in the scale for the running coupling affect significantly its absolute value (NNLO corrections needed?)

Yet another issue: Where to switch from kt-factorization to hybrid formalism? $\quad x_{1(2)} \sim \dfrac{m_t}{\sqrt{s}} \exp(\pm y_h)$
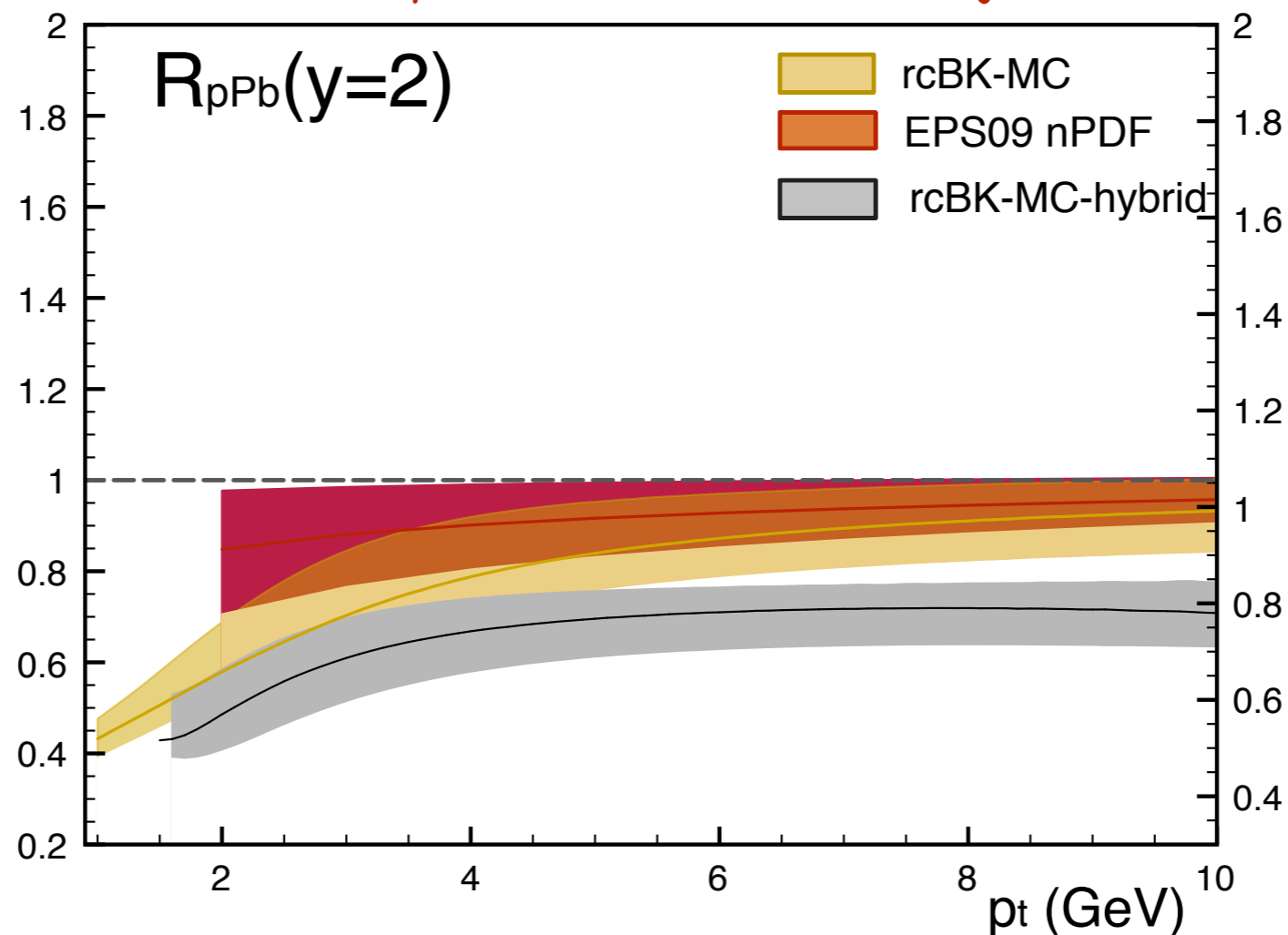
Midrapidity: kt-factorization:

$$\frac{dN^g}{d\eta \, d^2 p_t} \sim \phi^p(x_1) \otimes \phi^{Pb}(x_2)$$

Forward rapidity: hybrid formalism

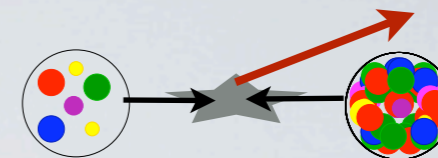$$\frac{dN}{d\eta \, d^2 p_t} \sim pdf^p(x_1) \otimes \phi^{Pb}(x_2)$$

Preliminary results. JLA-Dumitru-Fujii-Nara

$R_{pPb}(y=2)$
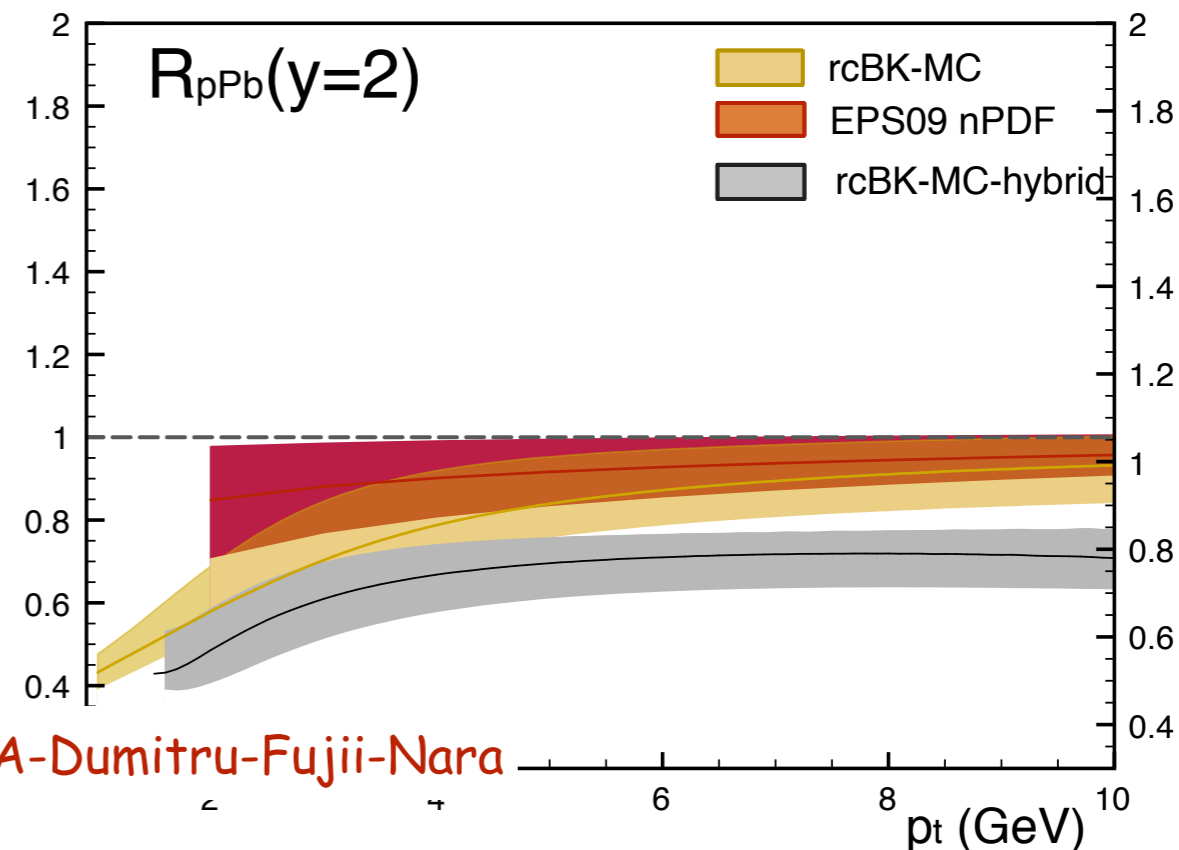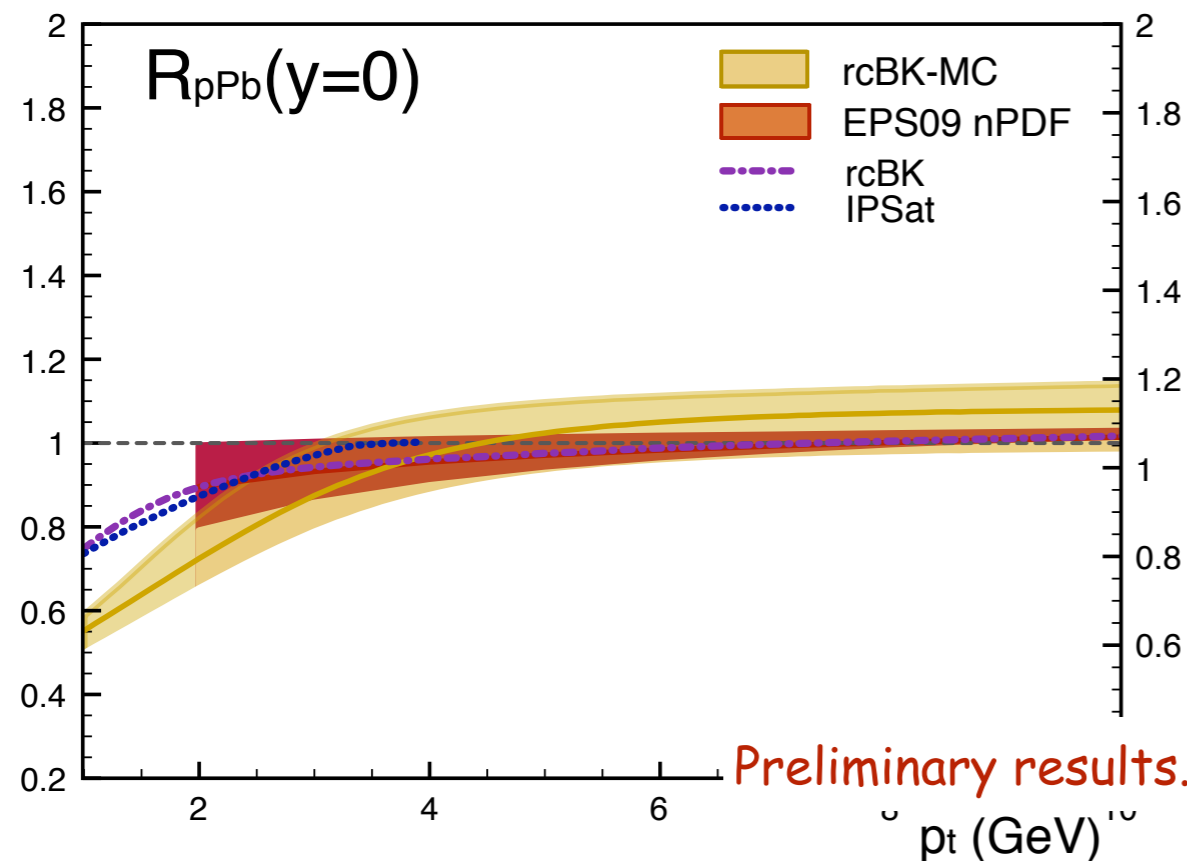
Legend: rcBK-MC, EPS09 nPDF, rcBK-MC-hybrid

p_t (GeV)

The inclusion of the inelastic term brings closer the hybrid and kt-fact results *Jaliian-Marian & Rezaeian*

R$_{pPb}$(y=0) — rcBK-MC, EPS09 nPDF, rcBK, IPSat
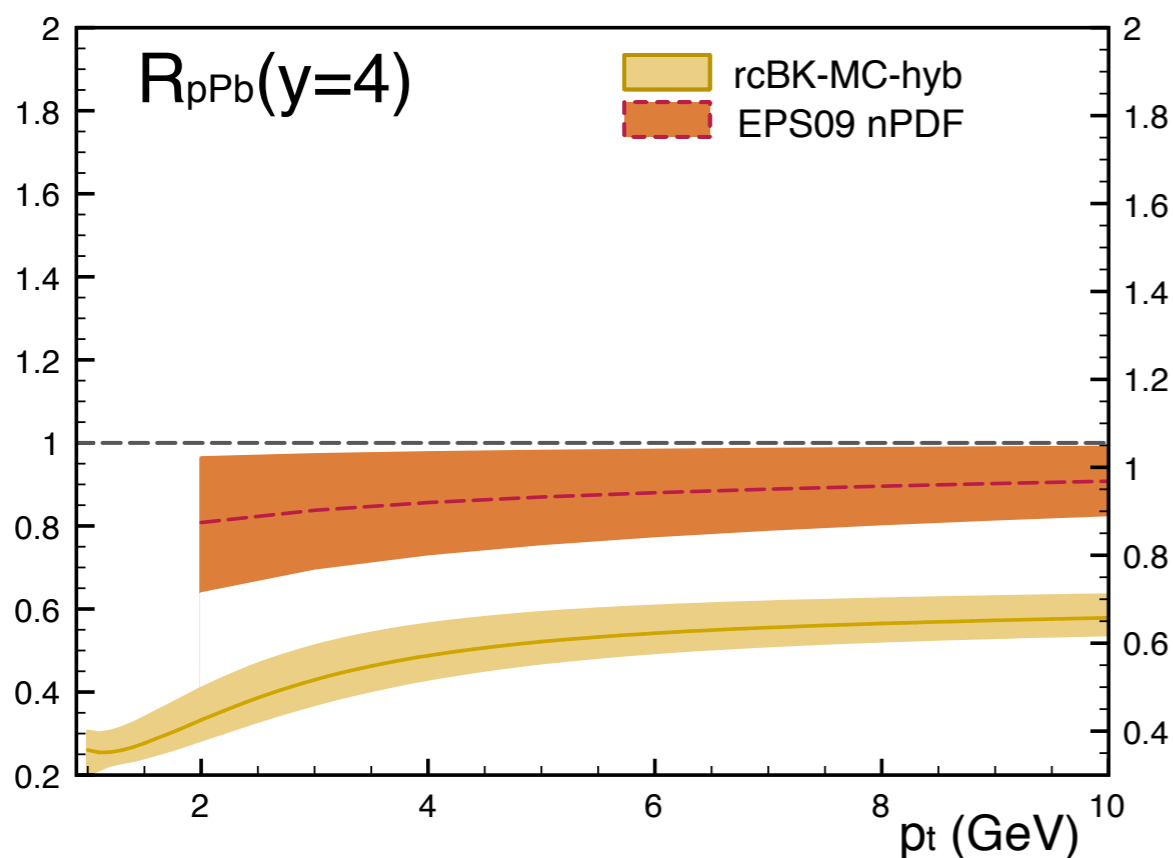
R$_{pPb}$(y=2) — rcBK-MC, EPS09 nPDF, rcBK-MC-hybrid

Preliminary results. JLA-Dumitru-Fujii-Nara

R$_{pPb}$(y=4) — rcBK-MC-hyb, EPS09 nPDF

R$_{pPb}$(y=6) — rcBK-MC-hyb, EPS09 nPDF

Forward di-hadron angular correlations
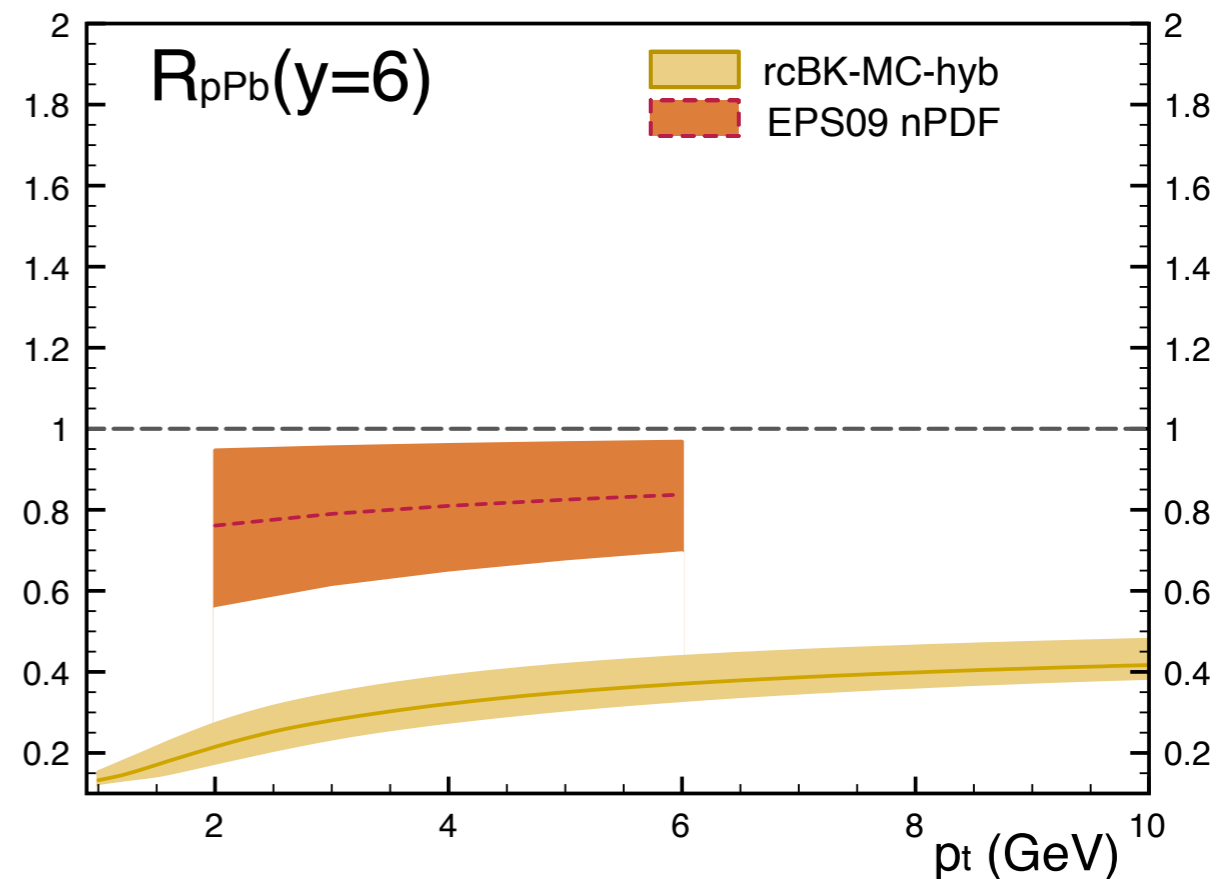
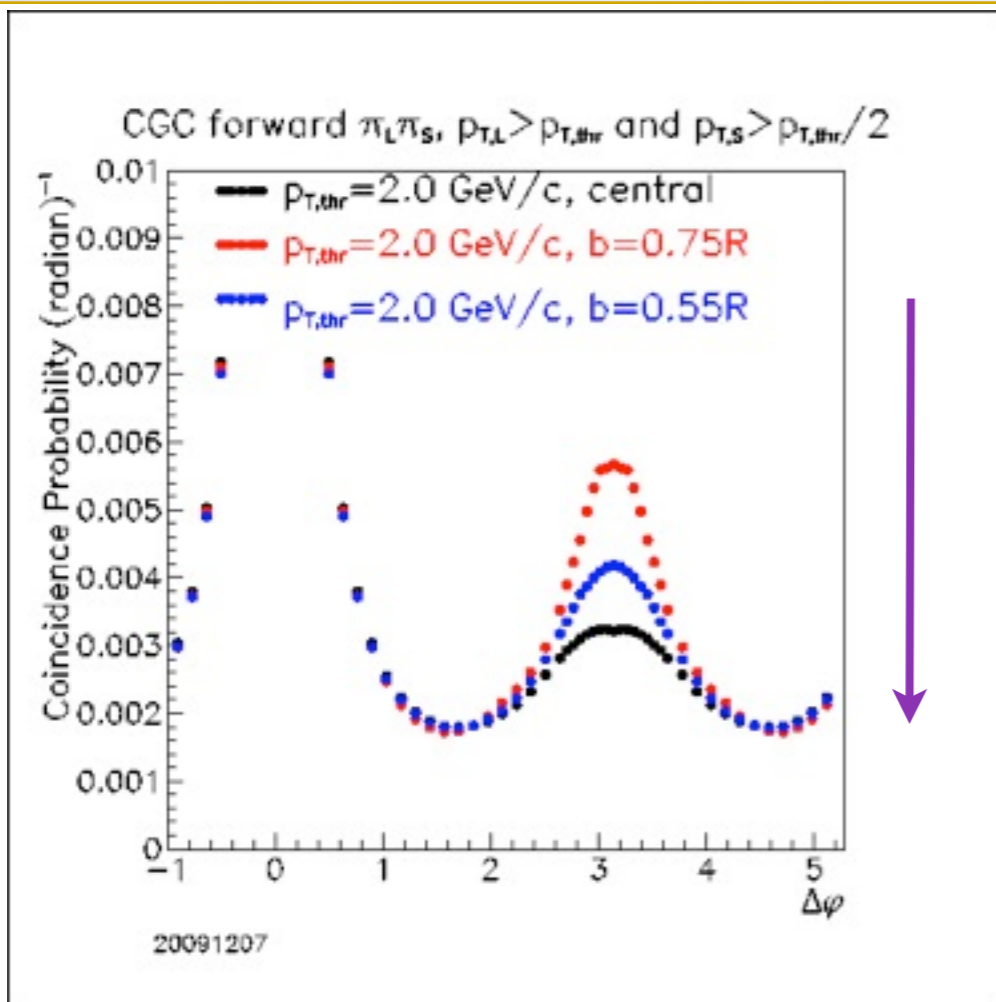**CGC description**: A quark (gluon) emits a gluon. The pair scatters independently off the target
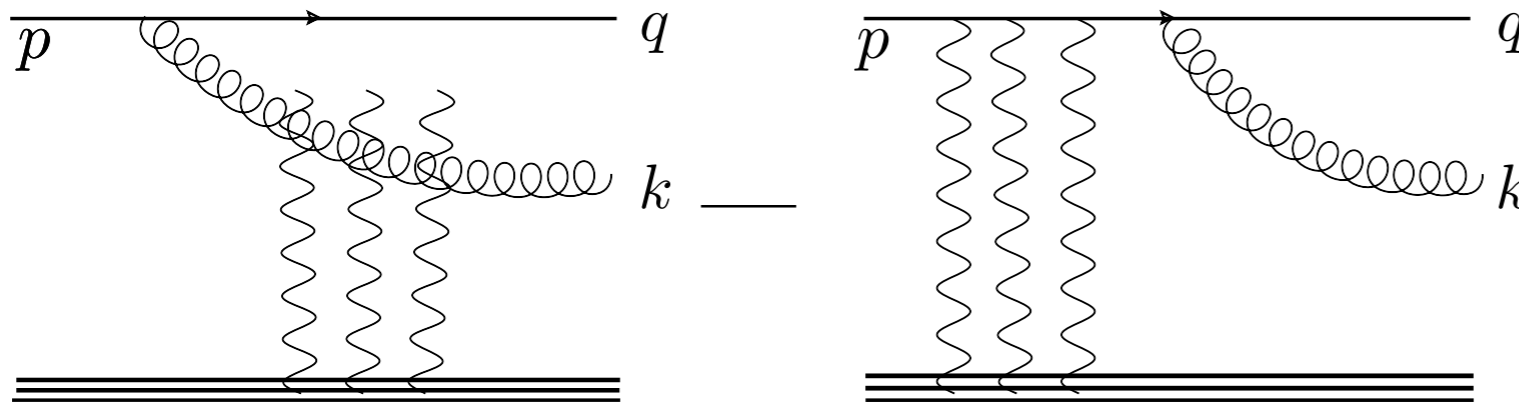
$$x_p = \frac{|k_1|e^{y_1} + |k_2|e^{y_2}}{\sqrt{s}}$$

$$x_A = \frac{|k_1|e^{-y_1} + |k_2|e^{-y_2}}{\sqrt{s}}$$

At small-x, the transverse momentum transfer is controlled by the saturation scale

Angular decorrelation happens if $\mathbf{Q_s^{Pb}(x_A) \sim (k_1, k_2)}$
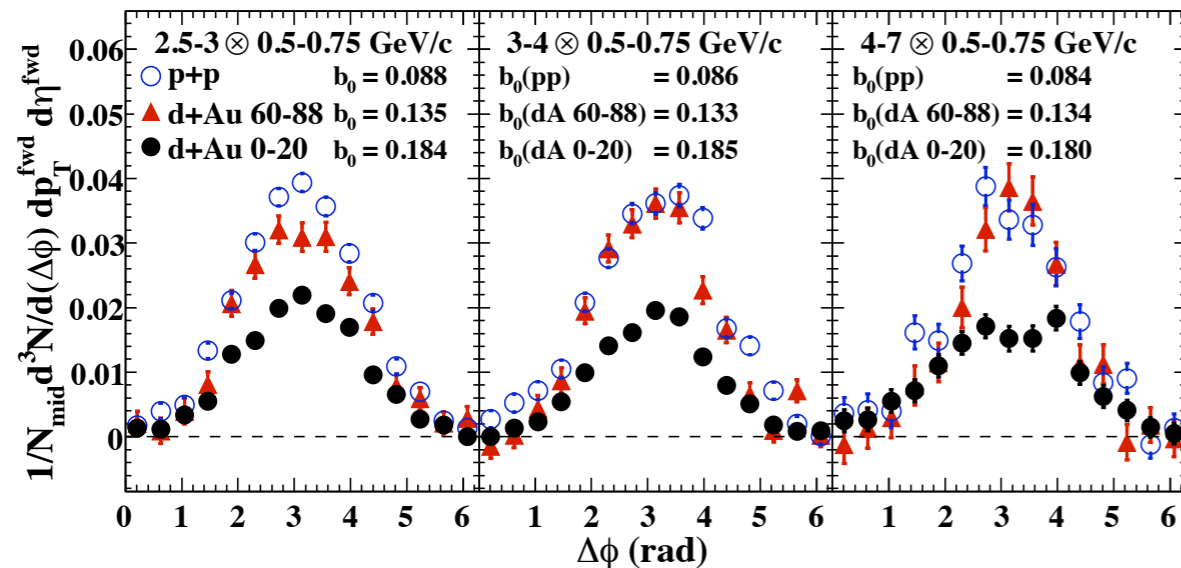

➡ Coincidence probability
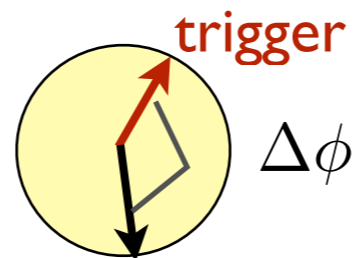
$$CP(\Delta\phi) = \frac{1}{N_{trig}} \frac{dN_{pair}}{d\Delta\phi}$$

Ergo, decorrelation should be stronger with
 • Increasing rapidity of the pair
 • Increasing collision centrality
 • Decreasing hadron momentum

Forward di-hadron angular correlations in RHIC dAu data

central-forward

$$J_{dA} = I_{dA} \times R^t_{dA} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\sigma^{\mathrm{pair}}_{dA} / \sigma_{dA}}{\sigma^{\mathrm{pair}}_{pp} / \sigma_{pp}}$$

central-forward panels:

2.5-3 ⊗ 0.5-0.75 GeV/c
- ○ p+p   b₀ = 0.088
- ▲ d+Au 60-88 b₀ = 0.135
- ● d+Au 0-20   b₀ = 0.184

3-4 ⊗ 0.5-0.75 GeV/c
- b₀(pp)   = 0.086
- b₀(dA 60-88) = 0.133
- b₀(dA 0-20)   = 0.185

4-7 ⊗ 0.5-0.75 GeV/c
- b₀(pp)   = 0.084
- b₀(dA 60-88) = 0.134
- b₀(dA 0-20)   = 0.180

Y-axis: $\frac{1}{N_{\mathrm{mid}}} \frac{d^3N}{d(\Delta\phi)\, dp_T^{\mathrm{fwd}}\, d\eta^{\mathrm{fwd}}}$

X-axis: $\Delta\phi$ (rad)

forward-forward

1.1-1.6 ⊗ 0.5-0.75 GeV/c
- ○ p+p
- ▲ d+Au 60-88
- ● d+Au 0-20
- b_0^{pp} = 0.095
- $b_0^{dA\ 60-88}$ = 0.141
- $b_0^{dA\ 0-20}$ = 0.176

1.6-2 ⊗ 0.5-0.75 GeV/c
- b_0^{pp} = 0.079
- $b_0^{dA\ 60-88}$ = 0.127
- $b_0^{dA\ 0-20}$ = 0.163

2-5 ⊗ 0.5-0.75 GeV/c
- b_0^{pp} = 0.059
- $b_0^{dA\ 60-88}$ = 0.106
- $b_0^{dA\ 0-20}$ = 0.142

Y-axis: $\frac{1}{N_{\mathrm{clus}}} \frac{d^3N}{d(\Delta\phi)\, dp_T^{\pi^0}\, d\eta^{\pi^0}}$

X-axis: $\Delta\phi$ (rad)

Right plot (PHENIX data):

peripheral

central

J_{dA}

d+Au 60-88 p_T^{fwd}
- ○ 0.5-0.75 GeV/c
- □ 0.75-1.0 GeV/c
- △ 1.0-1.5 GeV/c

d+Au 0-20 p_T^{fwd}
- ● 0.5-0.75 GeV/c
- ■ 0.75-1.0 GeV/c
- ▲ 1.0-1.5 GeV/c

X-axis: $X_{\mathrm{Au}}^{\mathrm{frag}}$

PHENIX data

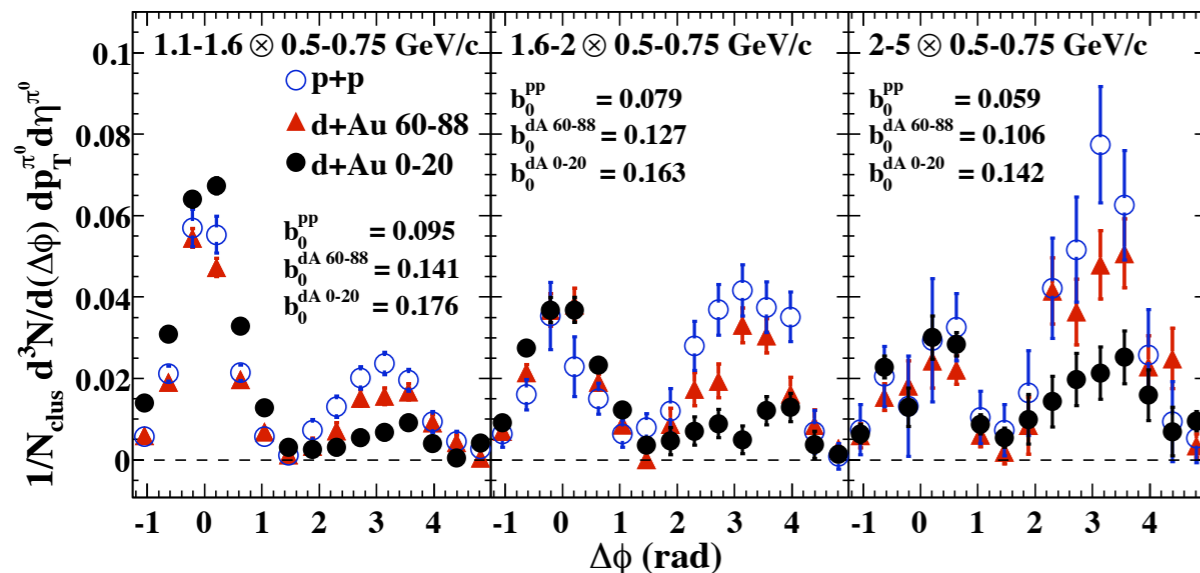Observed decorrelation IS stronger with
- Increasing rapidity of the pair
- Increasing collision centrality
- Decreasing hadron momentum

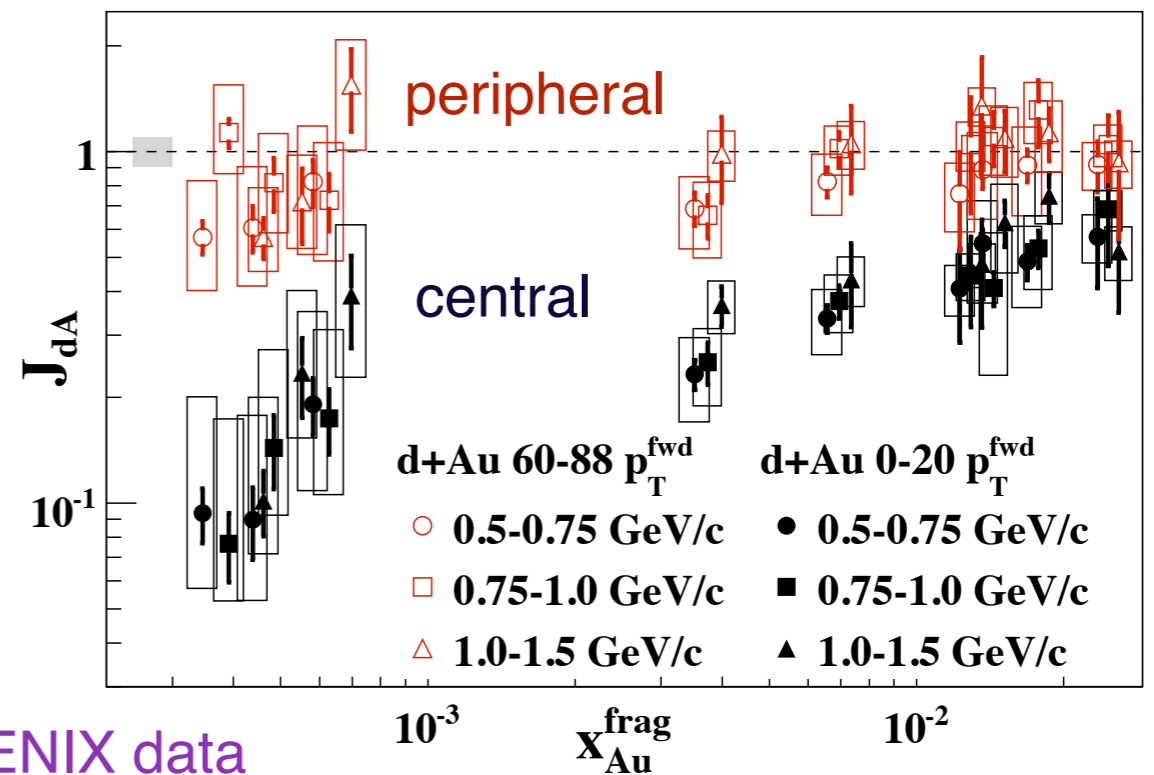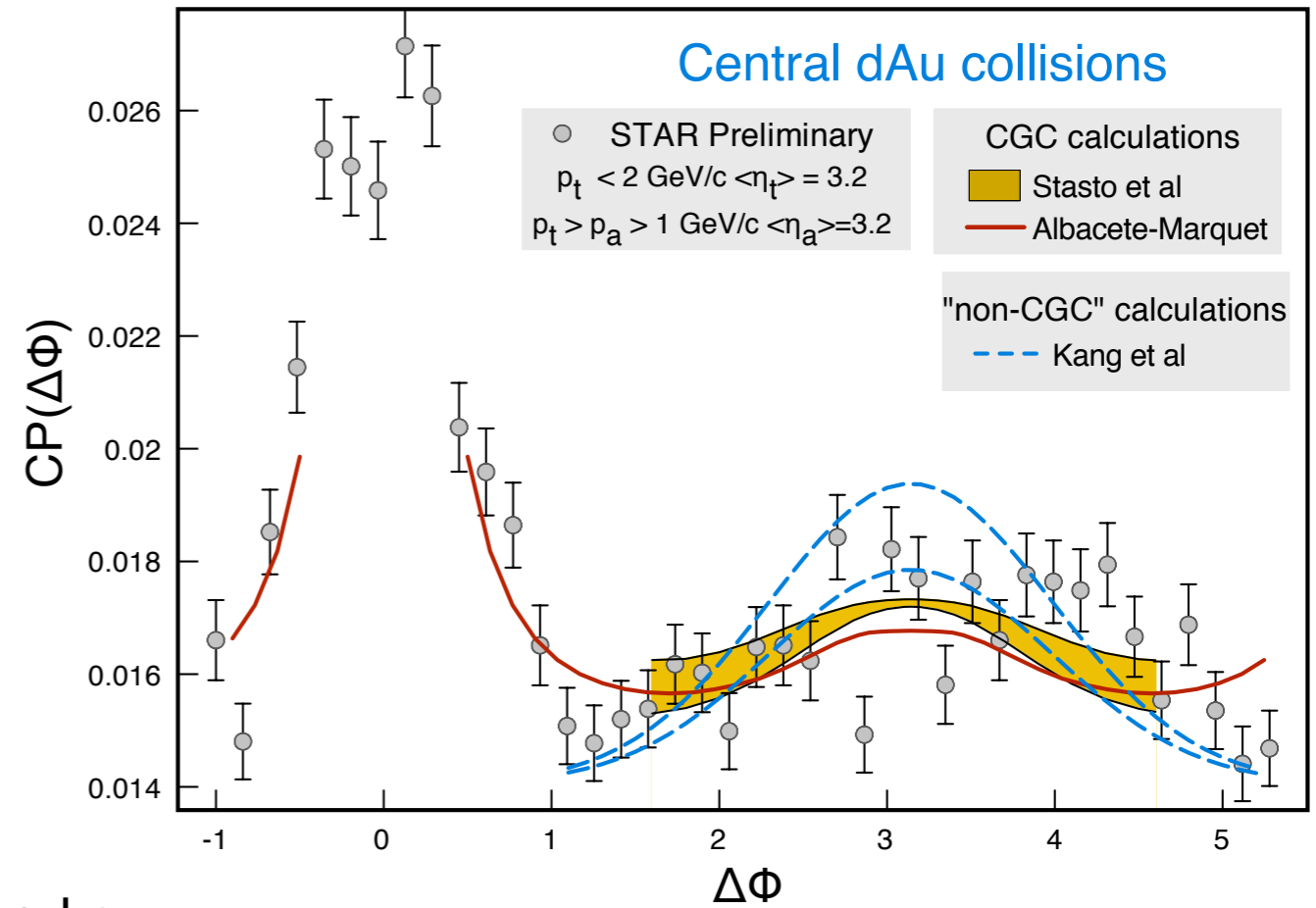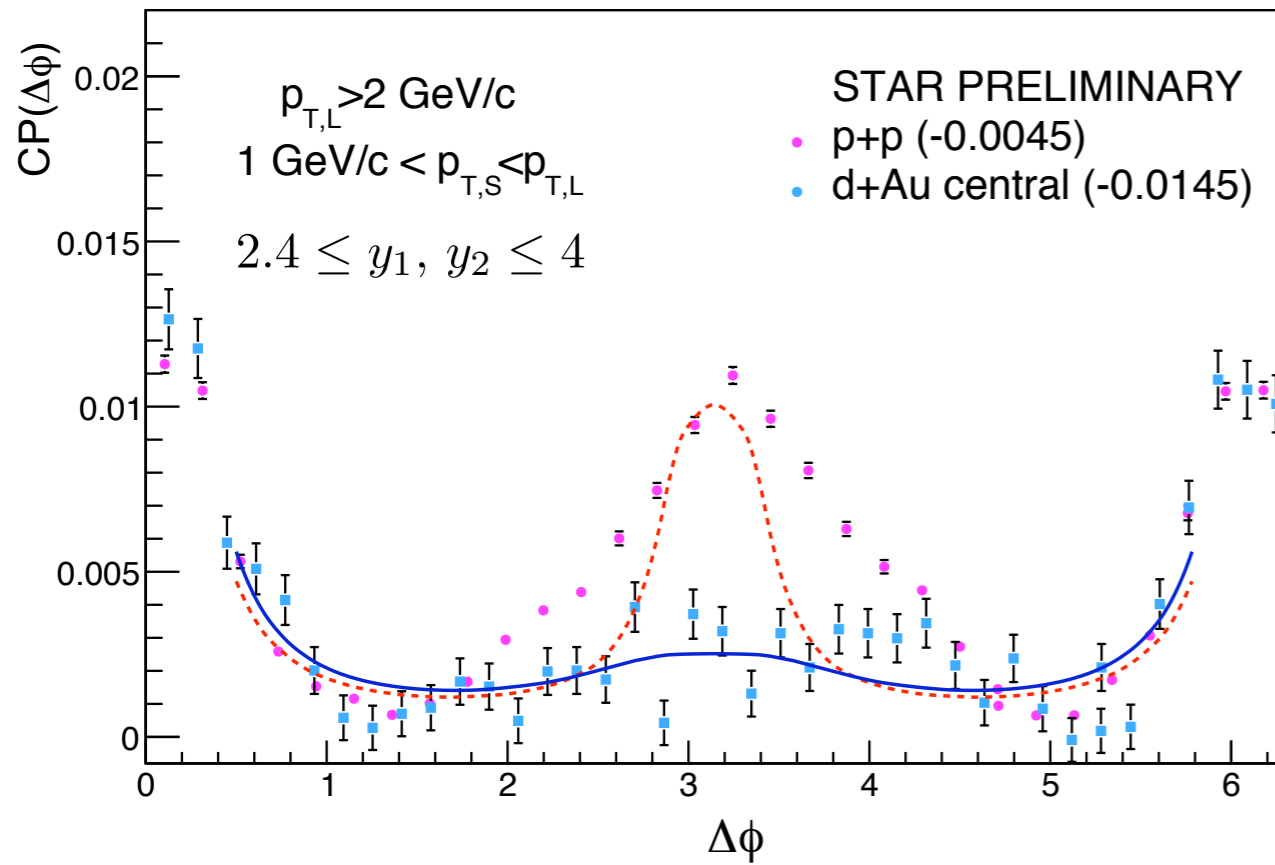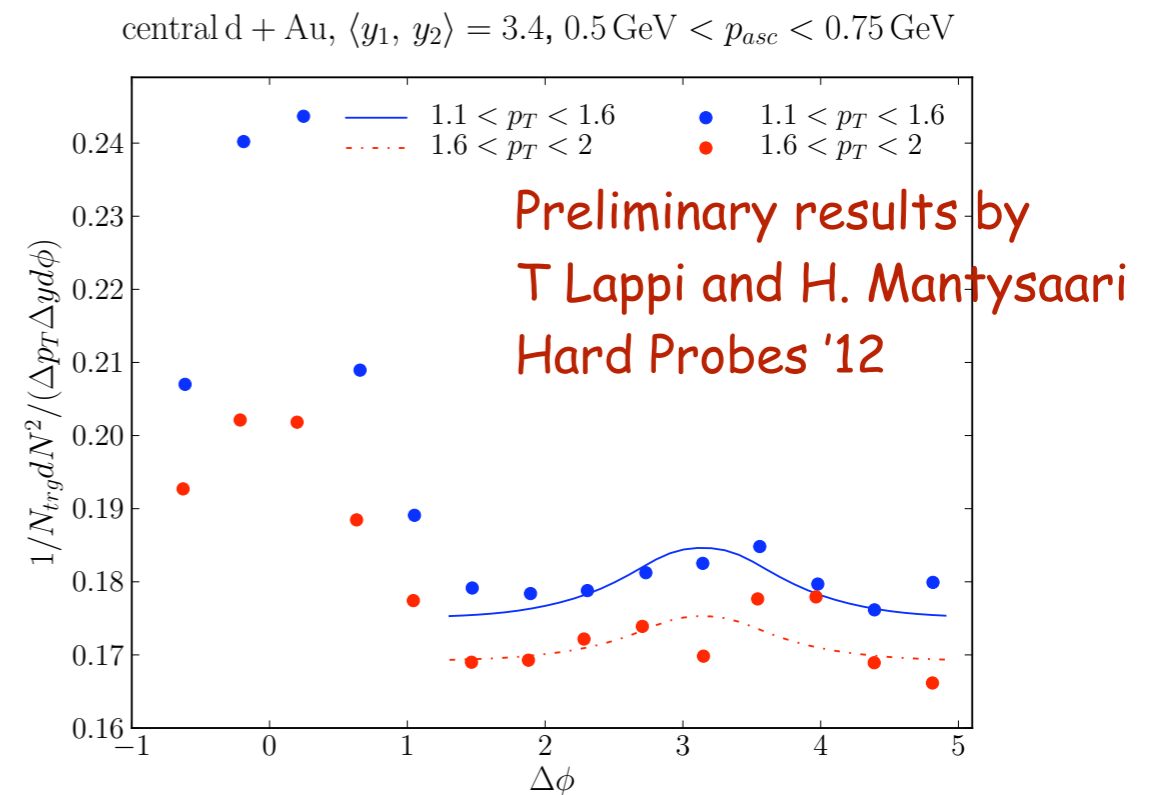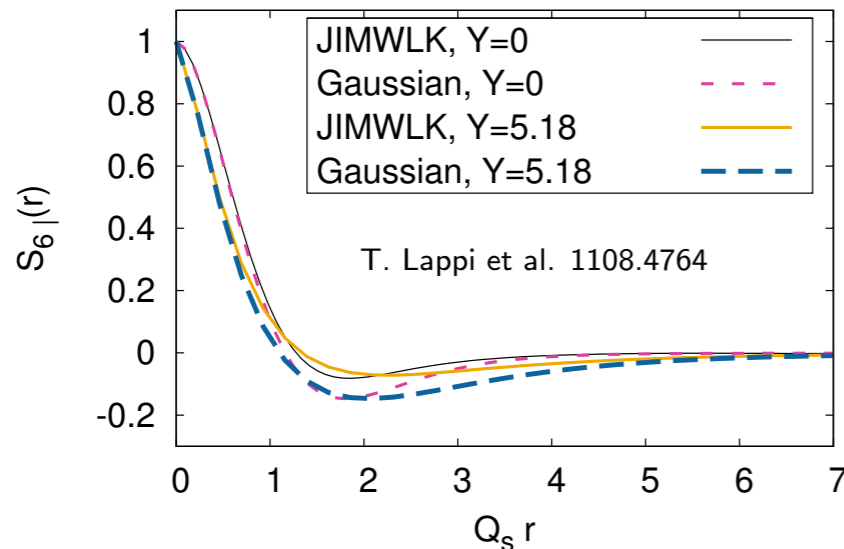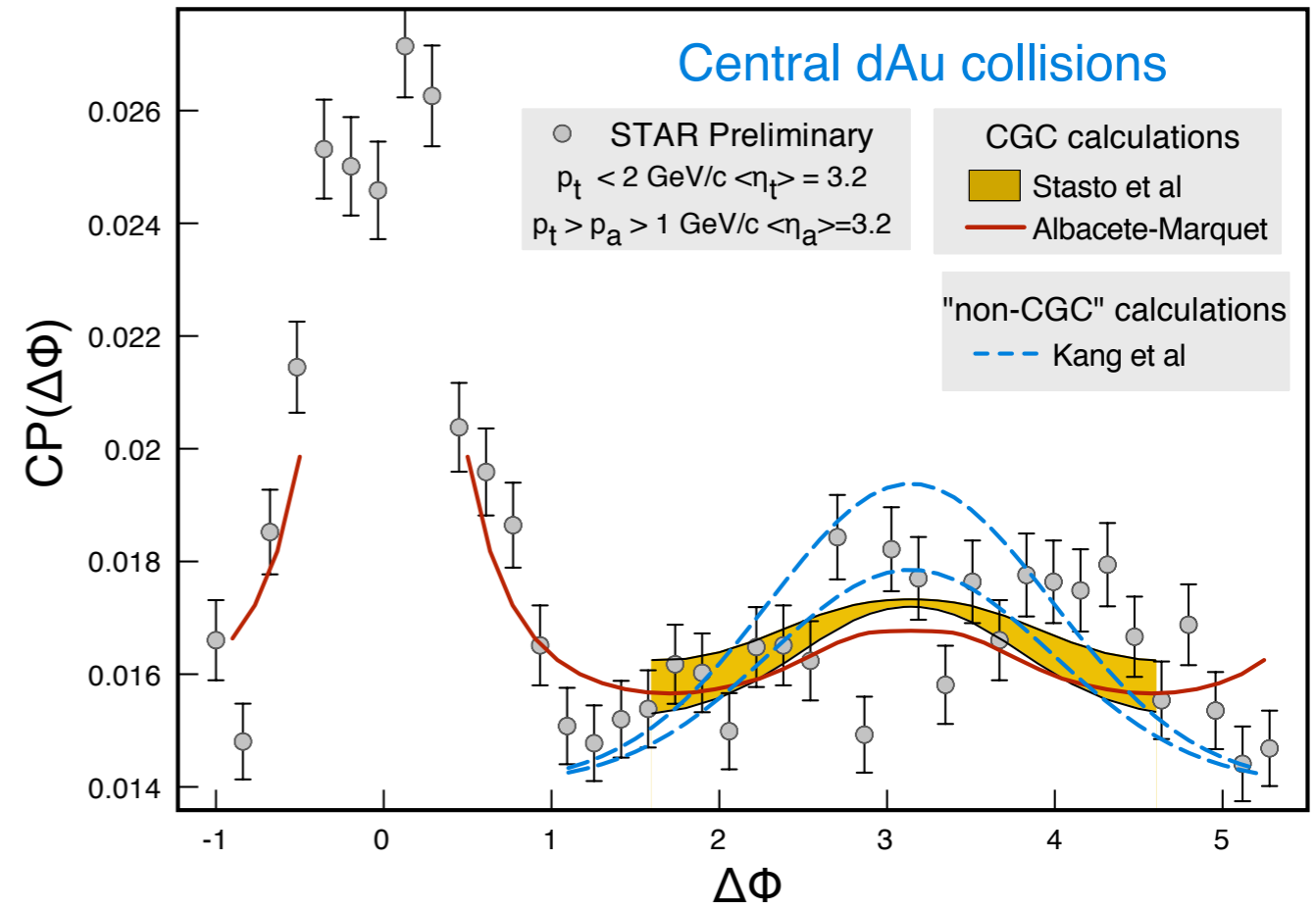# Forward di-hadron angular correlations in RHIC dAu data

$p_{T,L} > 2$ GeV/c

1 GeV/c $< p_{T,S} < p_{T,L}$

$2.4 \leq y_1, y_2 \leq 4$

STAR PRELIMINARY
- p+p (-0.0045)
- d+Au central (-0.0145)

Central dAu collisions

STAR Preliminary
$p_t < 2$ GeV/c $\langle\eta_t\rangle = 3.2$
$p_t > p_a > 1$ GeV/c $\langle\eta_a\rangle = 3.2$

CGC calculations
Stasto et al
Albacete-Marquet
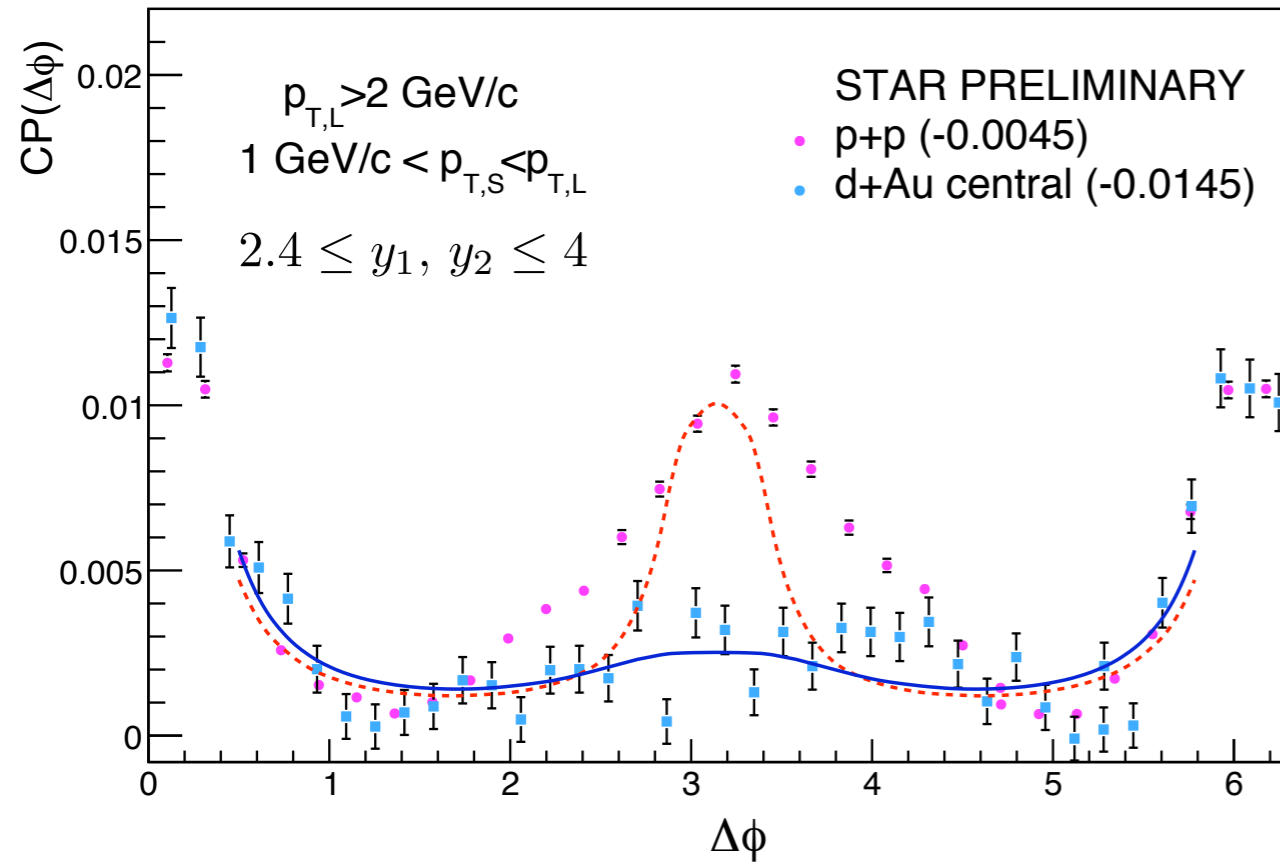
"non-CGC" calculations
Kang et al

Uncertainties in current CGC phenomenological works:
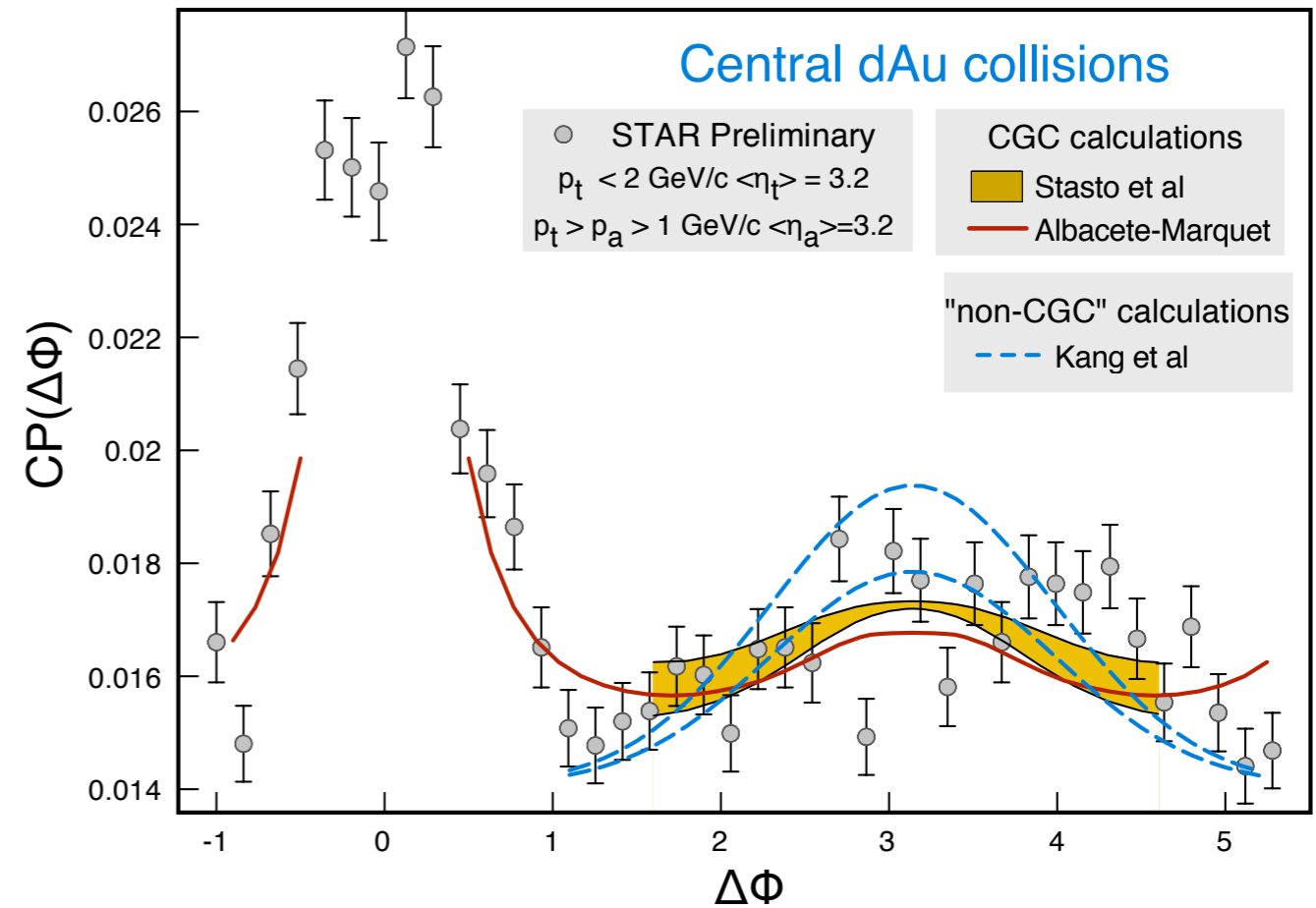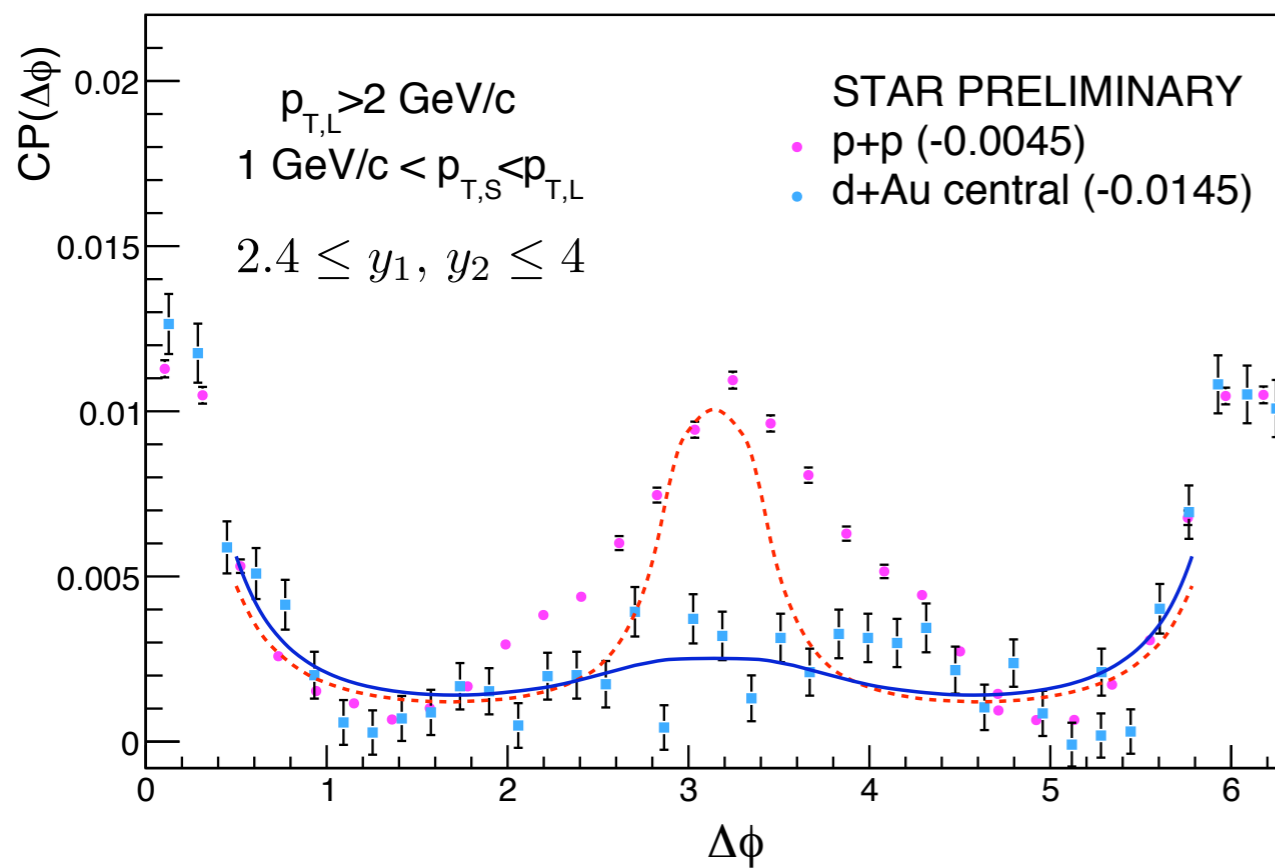- Need of a better description of n-point functions.

$$S^{(6)}(b, x, x', b') = Q(b, b', x', x)S(x, x') + \mathcal{O}\left(\frac{1}{N_c^2}\right)$$

JIMWLK, Y=0
Gaussian, Y=0
JIMWLK, Y=5.18
Gaussian, Y=5.18

naive approximation, Y=0
JIMWLK, Y=5.18
naive approximation, Y=5.18

T. Lappi et al. 1108.4764

central d + Au, $\langle y_1, y_2 \rangle = 3.4$, $0.5\,\mathrm{GeV} < p_{asc} < 0.75\,\mathrm{GeV}$

$1.1 < p_T < 1.6$
$1.6 < p_T < 2$
$1.1 < p_T < 1.6$
$1.6 < p_T < 2$

Preliminary results by
T Lappi and H. Mantysaari
Hard Probes '12

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Forward di-hadron angular correlations in RHIC dAu data

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CGC calculations
- Stasto et al
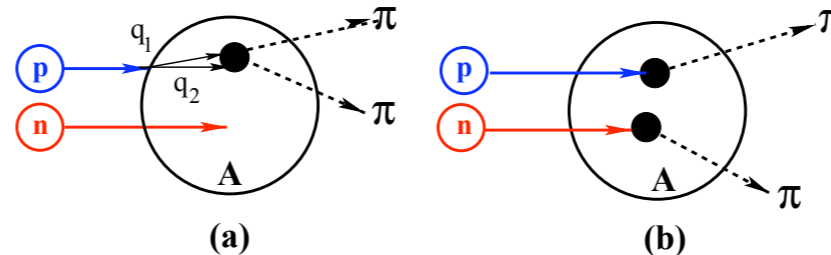- Albacete-Marquet

"non-CGC" calculations
- Kang et al

Uncertainties in current CGC phenomenological works:
- Need of a better description of n-point functions.
- Better determination of the pedestal: K-factors in single inclusive production? Role of double parton scattering?

Strikman-Vogelsang

Strikman, Vogelsang, 1009.6123

- Alternative descriptions including resummation of multiple scatterings, nuclear shadowing and cold nuclear matter energy loss seem possible... [Kang et al]

Outlook

✔ Important steps have been taken in promoting GCG to an useful quantitative tool
   - Continuos progress on the theoretical side
   - Phenomenological effort to systematically describe data from different
     systems (e+p, e+A, p+p, d+Au, Aa+Au and Pb+Pb) in an unified framework

✔ Observed suppression phenomena in RHIC forward data provide the most
   compelling evidence for the relevance of CGC effects in presently available data

✔ However, RHIC data lies at the limit of applicability of the high-energy CGC
   formalism. Missing dynamical effects and higher order corrections may modify the
   interpretation of data

✔ More differential studies of data are needed to distinguish the CGC approach
   from others
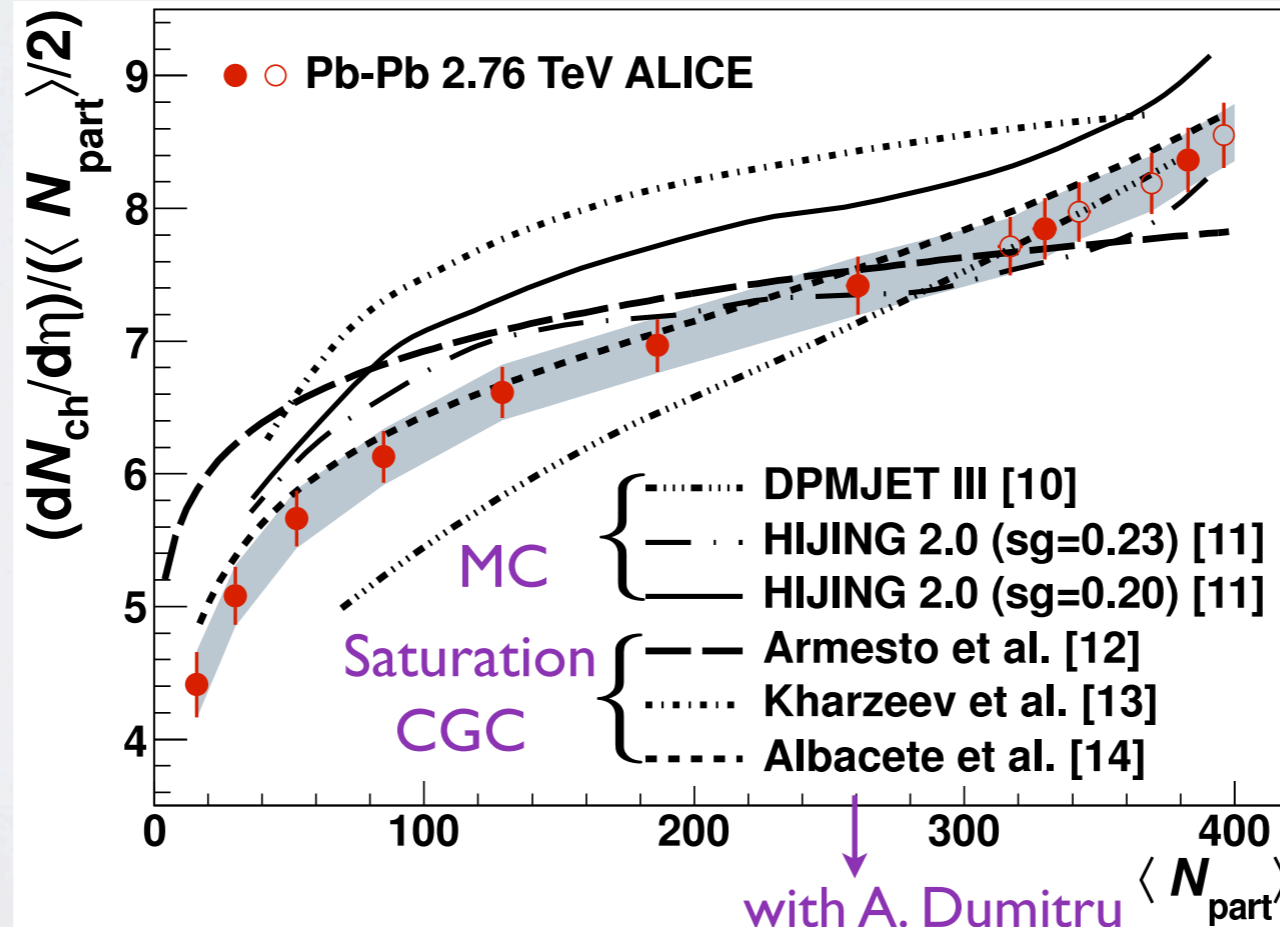
Thanks!

Back up

Color Glass Condensate models

charged particles ~ # small-x gluons in the wave functions of the colliding nuclei
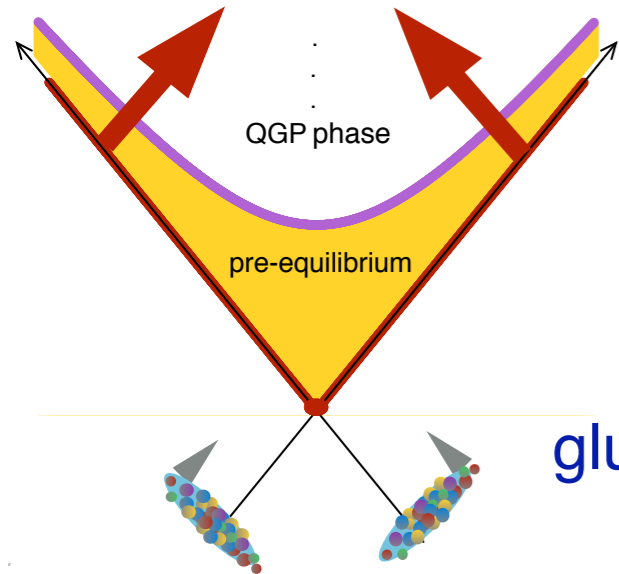
LO kt-factorization:
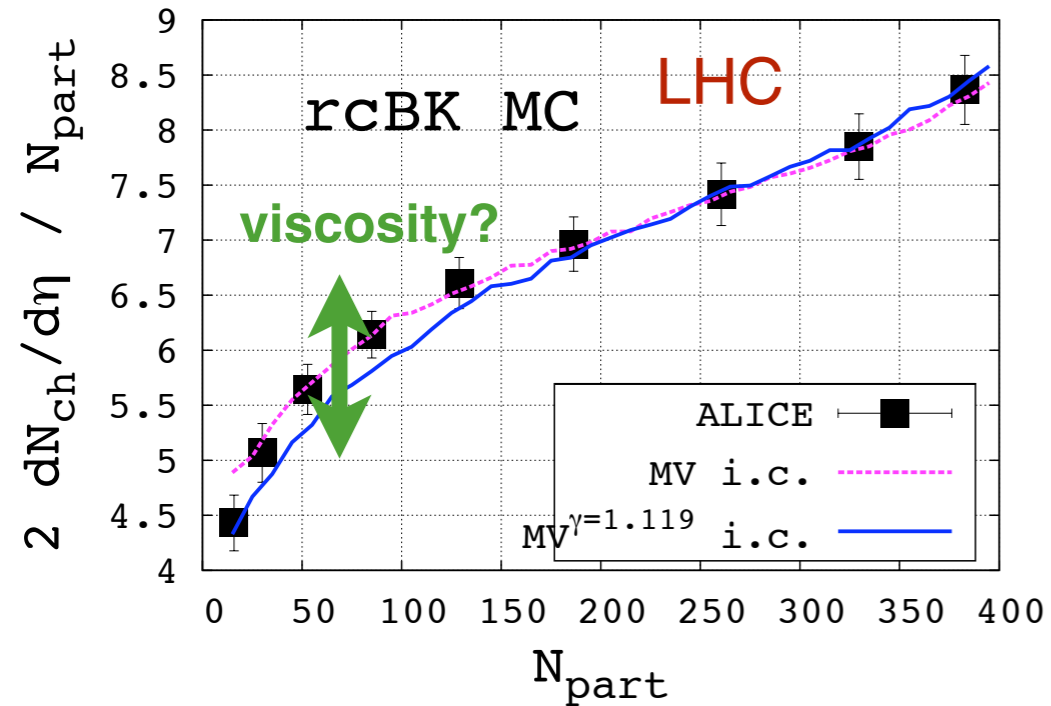$$\left.\frac{dN^g}{d\eta\,d^2p_t}\right|_{\eta=0} \propto \frac{1}{p_t^2} \int d^2k_t\,\alpha_s\,\phi(x_1,k_t)\,\phi(x_2,|p_t - kt|)$$

$$\lambda \approx 0.24 \div 0.3$$

gluon-hadron duality:
$$\left.\frac{dN^{ch}}{d\eta}\right|_{\eta=0} = \frac{2}{3}K\left.\frac{dN^g}{d\eta}\right|_{\eta=0} \propto Q_s^2(\sqrt{s},b) \sim \sqrt{s/s_0}^{\lambda} N_{part}$$

● ○ Pb-Pb 2.76 TeV ALICE

MC { DPMJET III [10]
    HIJING 2.0 (sg=0.23) [11]
    HIJING 2.0 (sg=0.20) [11]

Saturation { Armesto et al. [12]
CGC   { Kharzeev et al. [13]
             Albacete et al. [14]

with A. Dumitru $\langle N_{part} \rangle$

- CGC gives a very good descriptions of bulk features of multiparticle production
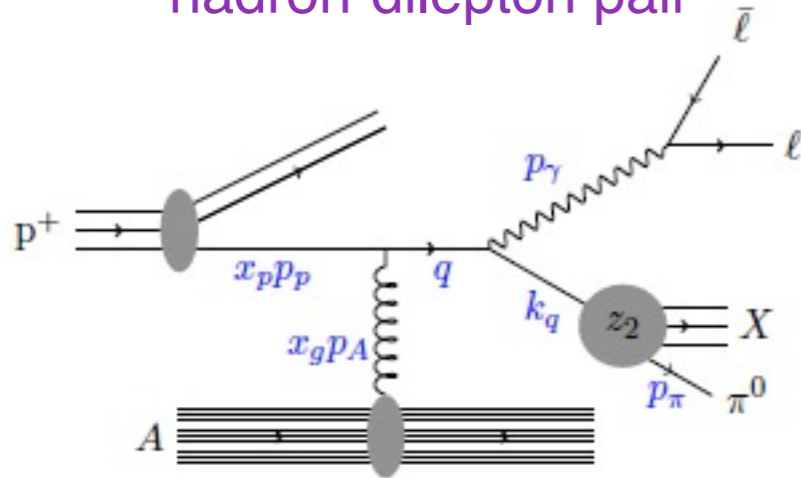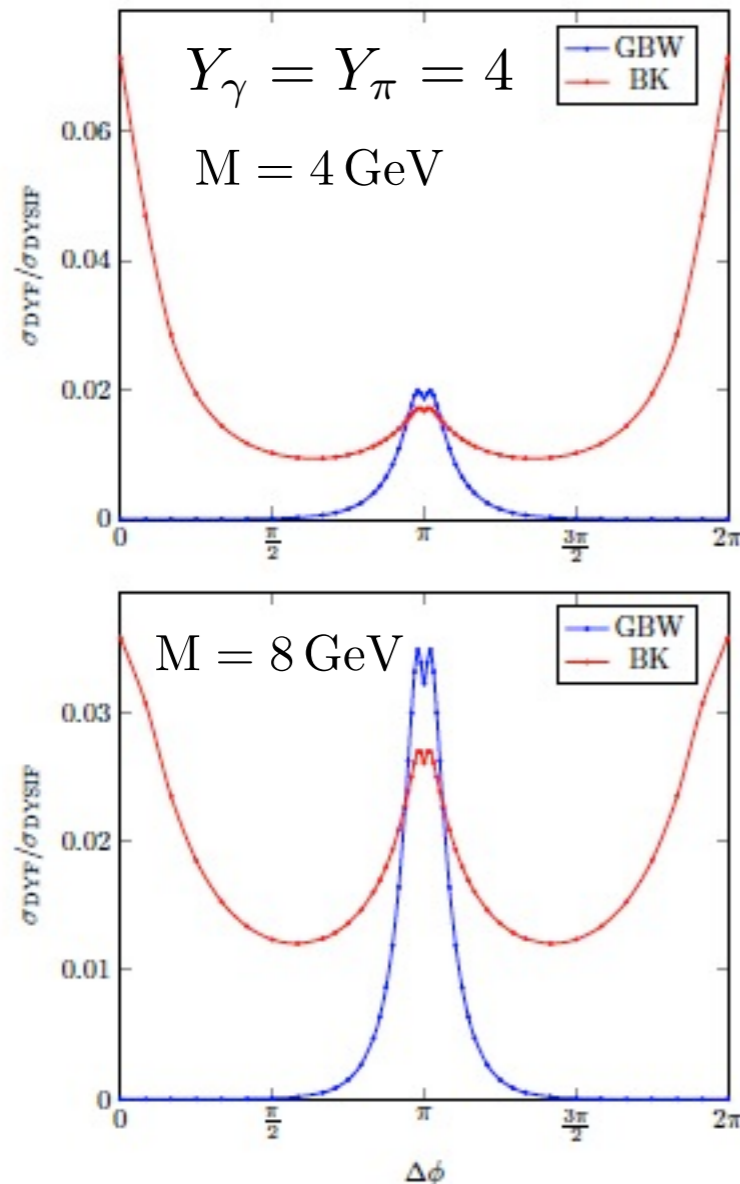

CGC: Non-linear and non-local

Knowledge of the "hard" part of nuclear UGD would further constrain the description of the initial state!

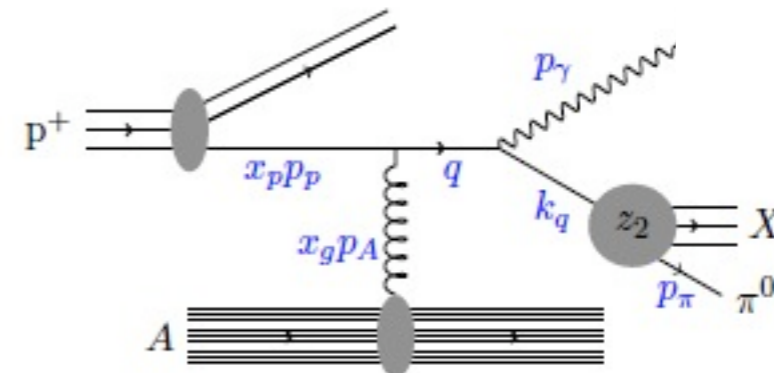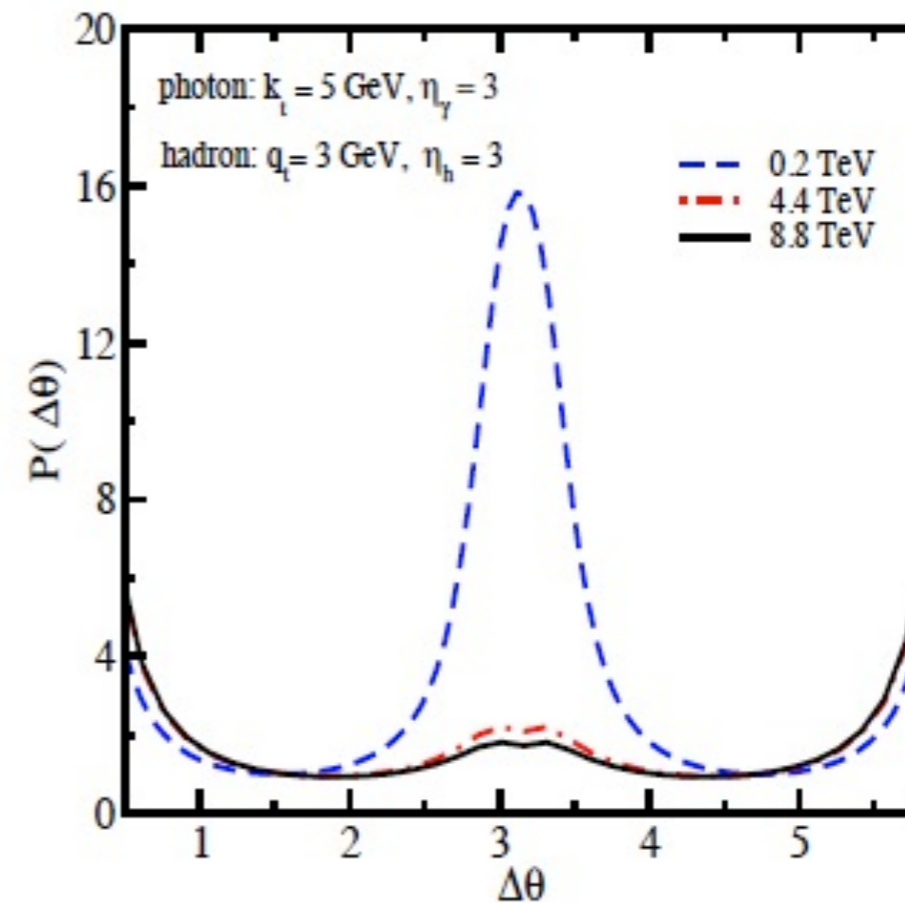# hadron-photon* correlations in pPb collisions at the LHC

• hadron-dilepton pair

Stasto et al 1204.4861

$$Y_\gamma = Y_\pi = 4$$

$$M = 4\,\text{GeV}$$

$$M = 8\,\text{GeV}$$

• hadron-photon

Jalilian-Marian's talk

photon: $k_t = 5\,\text{GeV}$, $\eta_\gamma = 3$

hadron: $q_t = 3\,\text{GeV}$, $\eta_h = 3$

0.2 TeV
4.4 TeV
8.8 TeV

These processes are theoretically cleaner:
Only knowledge of 2-point needed!!